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Annual Report

Covering the Period August 15, 1972 through August 15, 1973

TECHNOLOGY TRANSFER — TRANSPORTATION

By: TOM ANYOS
RUTH LIZAK
DAVID MERRIFIELD

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
TECHNOLOGY UTILIZATION OFFICE
NASA HEADQUARTERS
WASHINGTON, D.C. 20546
Attention: MR. RICHARD MINER

CONTRACT NASw-2455

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STANFORD RESEARCH INSTITUTE
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September 1973

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SRI Project PYU-2201

Approved by:

MARION E. HILL, *Director*
Chemistry Laboratory

CHARLES J. COOK, *Executive Director*
Physical Sciences Division

✓

PREFACE

The NASA Technology Applications Team at Stanford Research Institute has been active in the technology transfer program since July 1, 1969. This is the first annual report under Contract NASw-2455; previous activities were covered under Contract NASw-1992. The overall objectives of the program are to transfer aerospace technology to the solution of important technological problems in public transportation and to implement and continuously refine appropriate methods for ensuring successful transfers and for providing appropriate visibility for program activities.

The program at SRI is supervised by Mr. Marion E. Hill, Director, Chemistry Laboratory, Physical Sciences Division. Dr. Charles J. Cook, Executive Director of the Physical Sciences Division, continues to take an active interest.

The members of the core Team at SRI during this report period were:

Dr. Tom Anyos, Program Director

Mr. David G. Merrifield, Research Engineer

Mrs. Ruth M. Lizak, Research Assistant

Miss Patricia A. Pantell, Secretary

The core Team also has the ability of drawing on the extensive and varied competence of the Institute's staff for solutions of specialized technical problems. This ability has allowed the Team to match key NASA technology to public sector problems outside the Team's direct expertise.

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I INTRODUCTION

Much of the wealth of scientific and technological information generated or accumulated by NASA in support of the nation's aerospace programs can be used by public agencies concerned with the everyday affairs of the people. Such a transfer of expertise, however, is not spontaneous. The applicable technical information first must be matched with needs. Implementation of the data is the equally important second phase. To these ends, NASA has established its Technology Utilization Office.

The NASA Technology Utilization Office has contracted with several research organizations throughout the country to assist in this program. Teams have been formed to actively transfer aerospace technology to the solution of public sector problems. The teams, called Technology Applications Teams (TAT), match the problems with aerospace solutions by working with public sector representatives who can clearly define the problems and with NASA scientists and engineers who are knowledgeable in the appropriate areas.

Stanford Research Institute (SRI) has operated a NASA-sponsored Team for four years. The SRI Team is currently concentrating on solving problems in the public transportation area and on developing methods for decreasing the time gap between the development and the marketing of new technology and for aiding the movement of knowledge across industrial, disciplinary, and regional boundaries.

The SRI TAT has developed a methodology that includes adaptive engineering of the aerospace technology and commercialization when a market is indicated (see Appendix D). It has become apparent to the SRI Team that commercial businesses must enter the process to transfer technology

successfully. In addition, the SRI Team has handled highway problems on a regional rather than a state basis, because many states in similar climatic or geologic regions have similar problems. Program exposure has been increased to encompass almost all of the fifty states (see Section II).

During FY 1973 the SRI Team interacted with thirty-two public sector agencies (see Appendix A). Although some contacts were brief and required only supplying needed information, many interactions continued throughout the year. These continuing interactions included adaptive engineering programs or technoeconomic study programs, or both. They are discussed in Section III. In addition, fifteen NASA innovations were being adapted for use on the highways or railways or were already entering the marketplace (see abstracts in Appendix B). Potential solutions for another four problems were being evaluated. The SRI TAT also initiated contact with two new transportation areas: urban mass transit and waterways.

Program visibility was provided by the Team through participation in several symposia and reviews and by coverage in Technology Mart magazine (see Appendix C). The Team continued its effort to enhance user confidence in the NASA technology transfer program.

II METHODOLOGY

During the past four years, the SRI Team has developed and continuously improved an operating philosophy and methodology for the effective and timely transfer of aerospace technology. The original methodology was aimed at getting to know the user and his problems. Methodologies were also established for interacting with the NASA centers and the Regional Dissemination Centers. During the third year of its operation, the TAT became aware of an increasing need for feasibility studies, adaptive engineering projects, market and technoeconomic surveys, and commercialization to complete the transfer of technology. A methodology was developed and followed whereby the TAT could verify the importance of the problem, the lack of a commercial solution, the technical and economic feasibility of adapting aerospace technology, and the subsequent business opportunity. During its fourth year, the Team became increasingly product-oriented, as it realized that the problem-originating public sector agency usually benefited from the technological solution only when a commercial product reached the marketplace.

The SRI TAT has thus recognized that commercial businesses must enter the process in order to transfer technology successfully. The Team member acts as a third-party transfer agent, interacting with the people who can define public sector technological problems, the NASA scientists and engineers who can bring technology to bear on these problems, and the businessmen who can convert the technology into products that solve the problem within the technical and economic limitations imposed by the market.

The Team member has certain functional activities to perform through the various phases of technology transfer. The nature of these functional responsibilities varies, depending on the level at which the transfer activity is pursued and the involvement of private interests in the process. These activities are clearly defined in the paper entitled "Technology Transfer" in Appendix D.

The Team plans to continue to refine this methodology during FY 1974. It may also work with the Regional Dissemination Center in an attempt to market technology more efficiently.

Regionalizing the TAT Effort

During its contacts with different states in the same general region of the country, the TAT has encountered a number of similar, if not identical, problems. The TAT feels that the NASA Technology Utilization Program would be served best if such problems were handled on a regional rather than a state basis. Program exposure would be dramatically enhanced and the TAT user list greatly increased, to encompass a major part of the country.

The TAT has chosen the Highway area for its initial approach to this concept. Personal, detailed contacts are developed with only one or two state highway departments in each region, those that express the most interest in working with the TAT and exhibit the greatest potential for co-funding. When the TAT uncovers a potential solution to a problem and it is successfully tested by the representative highway department, information on that technology is disseminated to all states in that region. In this way, the TAT effort is condensed and more effective. All fifty states benefit.

The country is being regionalized, initially, on the basis of climatic and geological conditions. When regions overlap, pertinent

information is disseminated to all appropriate states. In addition, the TAT is as responsive to the needs of individual states as time permits.

III STATUS OF TECHNOLOGY APPLICATIONS

Bridge Failure Detection

Federal regulations were passed in late 1970 requiring semiannual instrumented inspections of all highway bridges, because some bridges may be in jeopardy due to cracks not detectable by routine visual inspection. During a search for technology to enhance bridge inspection capabilities, the SRI TAT learned of a NASA-Ames technique called Randomdec. Randomdec monitors the structure's random vibration signature, using accelerometers as sensors.

A meeting between the technology innovators and representatives of the Federal Highway Administration was arranged by the SRI TAT in 1972. At this meeting the FHWA expressed interest in Randomdec and offered test support. The innovators, formerly of NASA-Ames, submitted a proposal to the FHWA for feasibility studies to test Randomdec in the laboratory on several small bridges, and perhaps on one large bridge.

Based on efforts by the TAT, a joint NASA/FHWA project was initiated in January 1973 by a transfer of funds from FHWA to NASA. Randomdec analysis is now being made of the response records of steel girders to random excitation. These records were provided by the FHWA from its ongoing experimental programs of fatigue testing of full-size steel girders. Signatures taken at different times are being compared to detect the growth of fatigue cracks. The relationship between flaw size and signature change is being established.

A very extensive study of signatures is being undertaken to determine the minimum detectable flaw size. Each response record is being studied at various frequency ranges and amplitude levels to ensure that

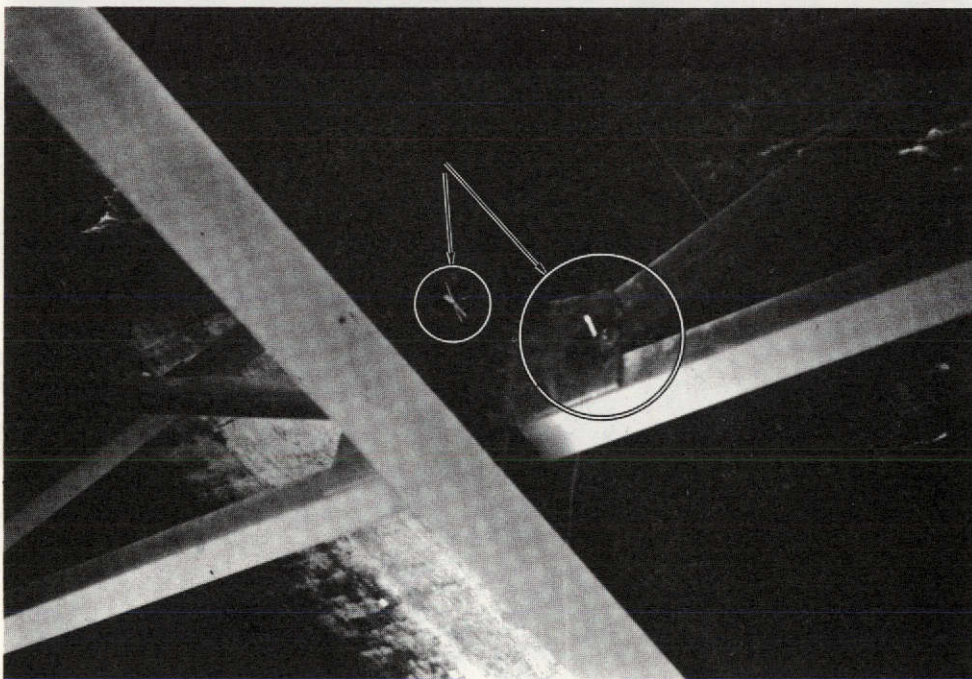
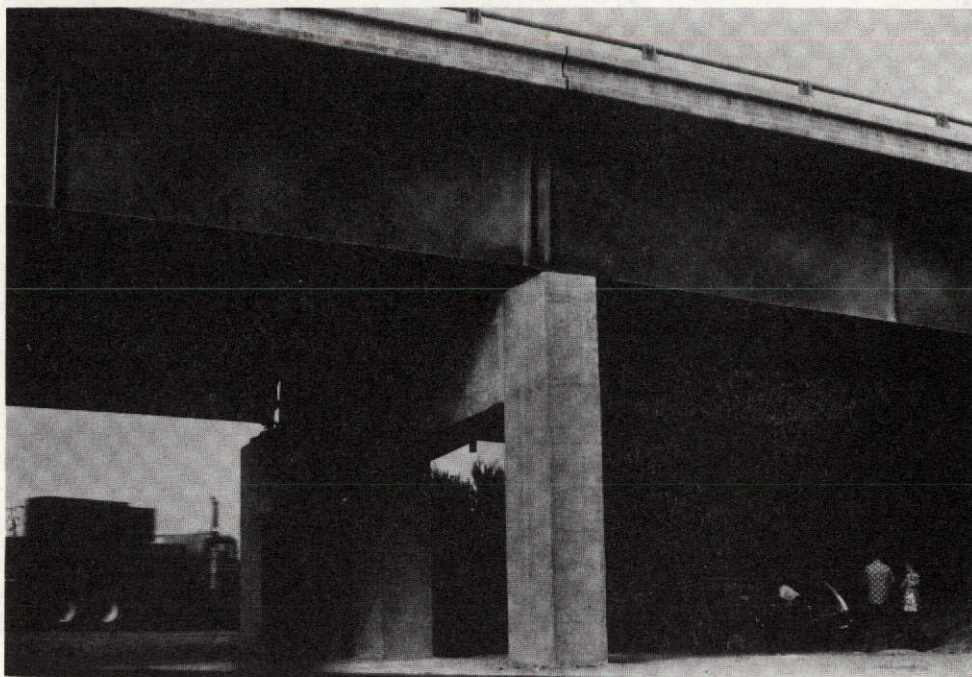
no visible signature change is missed. A critical flaw can be as small as 0.002 of beam cross section, an amount that does not affect damping.

A concurrent investigation is being conducted on a small bridge near NASA-Ames to determine environmental effects on the vibration signatures. Measurements are being taken at different times of the year to determine signature changes resulting from varying traffic and weather conditions. The SRI TAT has witnessed the instrumenting of the bridge and the data reduction. The test installation is shown in Figure 1. Accelerometers used to gather raw data are permanently mounted on the girders under the span. When data are gathered, these accelerometers are attached to the leads of a tape recorder. All vibratory information is stored in this manner until analysis by the Randomdec computer is required. Currently this analysis is performed at a NASA-Ames facility.

Improved Friction Material

The need for improved friction materials was expressed by three different TAT users for three different reasons. The Southern California Rapid Transit District was receiving citizen complaints about the noisy brakes on its buses. The U.S. Postal Service wanted to reduce the high maintenance costs resulting from short-lived brake linings on postal vehicles. The Association of American Railroads needed a friction material with less heat buildup for railcar brake shoes.

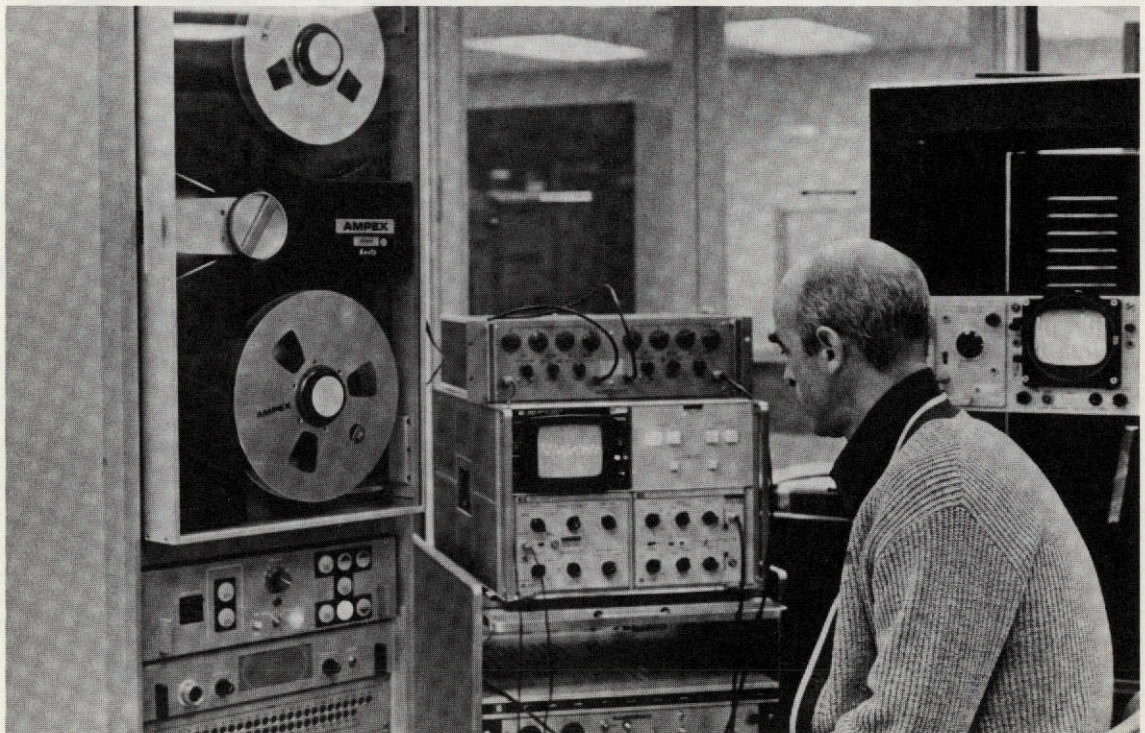
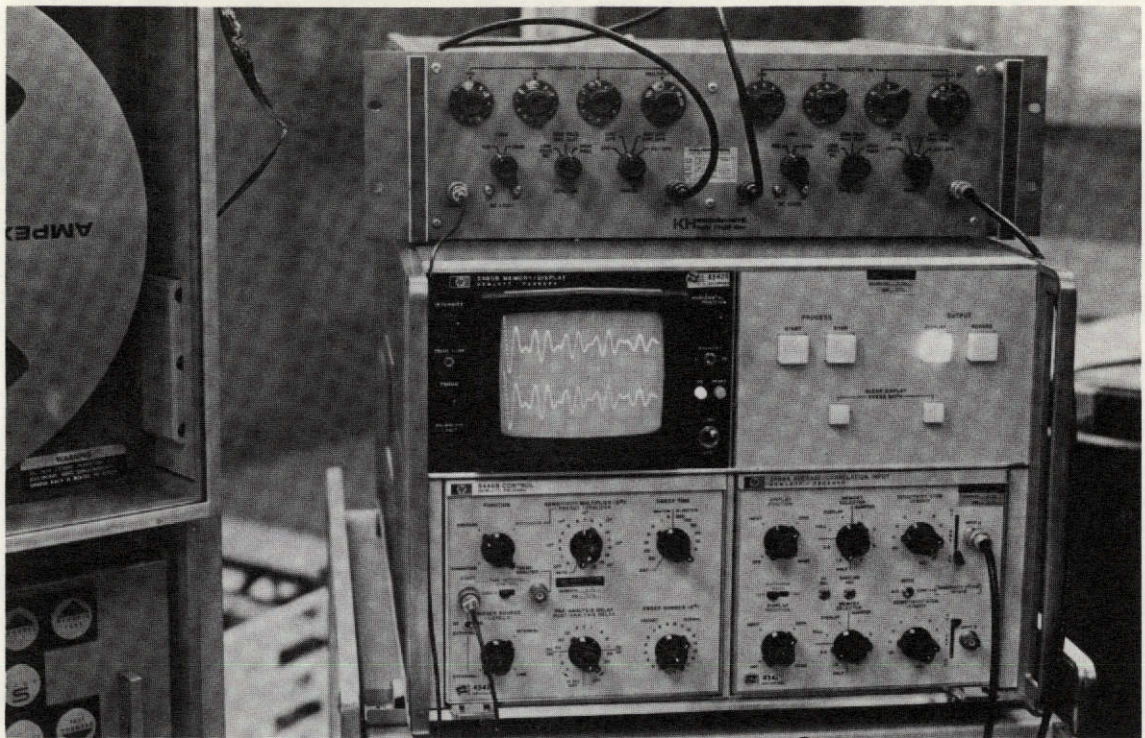
The TAT was aware of research under way at NASA-Ames on improved friction materials for SST brake linings. When approached by the TAT, the Ames scientists agreed to consider the problem. Specifications for bus and postal vehicle brakes were delivered to Ames along with samples of currently used brake shoes. Friction and wear testing on a Friction Assessment Screening Test Dynamometer showed the Ames material, which incorporated a polyphenylene polymer, to be two to eight times better than the materials now being used.



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FIGURE 1a INSTRUMENTING A HIGHWAY OVERPASS FOR RANDOMDEC ANALYSIS

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FIGURE 1b RANDOMDEC ANALYSIS OF VIBRATIONAL DATA

Through the efforts of the TAT, the SRI Polymers Group prepared 100 pounds of the polyphenylene polymer for Ames' further evaluation. After this evaluation, in March 1973, a NASA contract was negotiated with Bendix Corporation to fabricate brake shoes from the Ames material. Small-scale linings have been made from several materials (Figure 2). Following a screening process, the optimal combination of ingredients will be made into linings for testing on 1/4-ton postal vehicles.

Track/Train Dynamics Projects

As a result of the TAT's many interactions in railway problems and its close ties with key Association of American Railroads (AAR) researchers, the TAT became aware of the AAR's national research program to investigate track/train dynamics (TTD). This program was designed to model and analyze the dynamic interaction between track, truck (underbody), and car, and would lead to a better understanding of the rail environment and to improved rails and cars in the future. Through the TAT, the AAR and Federal Railroad Administration (FRA) learned of NASA's unique technology and capability in data acquisition and analysis, instrument development, and dynamic modeling.

An AAR/NASA-Marshall meeting, arranged by the SRI TAT, was held in November 1972 to discuss these capabilities. Marshall researchers were asked to contribute mathematical modeling, instrumentation, and dynamic analysis to the AAR Track/Train Dynamics Program. Later, the problem was defined in detail by the AAR, and the exact work to be done at Marshall was specified. A work statement was prepared and submitted in April 1973, and contract negotiations began. As a result of these negotiations, a transfer of funds in the amount of \$350,000-\$400,000 from the AAR-FRA to NASA-Marshall is expected in FY '73. These funds will support further NASA assistance for the solution of the problems involved in the TTD program.

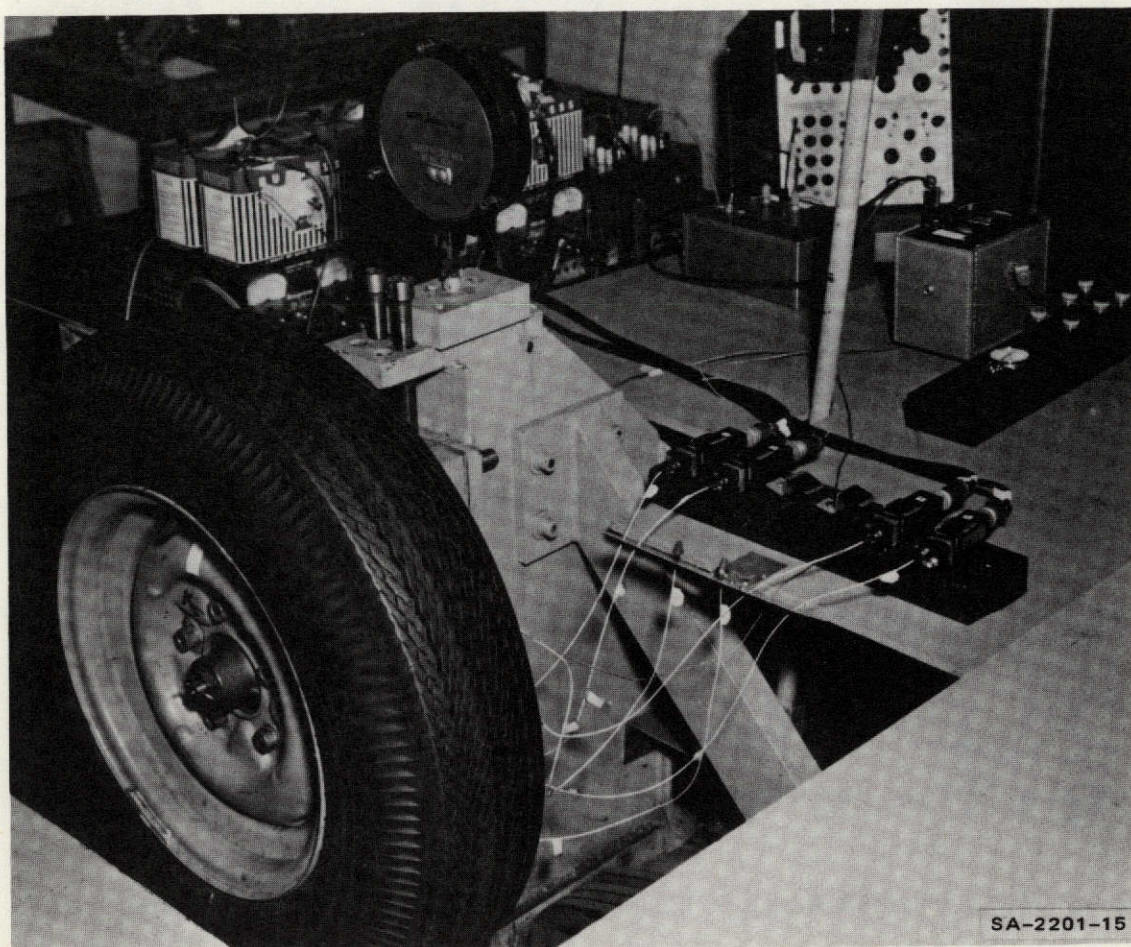


FIGURE 2 BRAKE SHOES CONTAINING NASA-AMES FRICTION MATERIAL

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Air Purification for Tollbooths

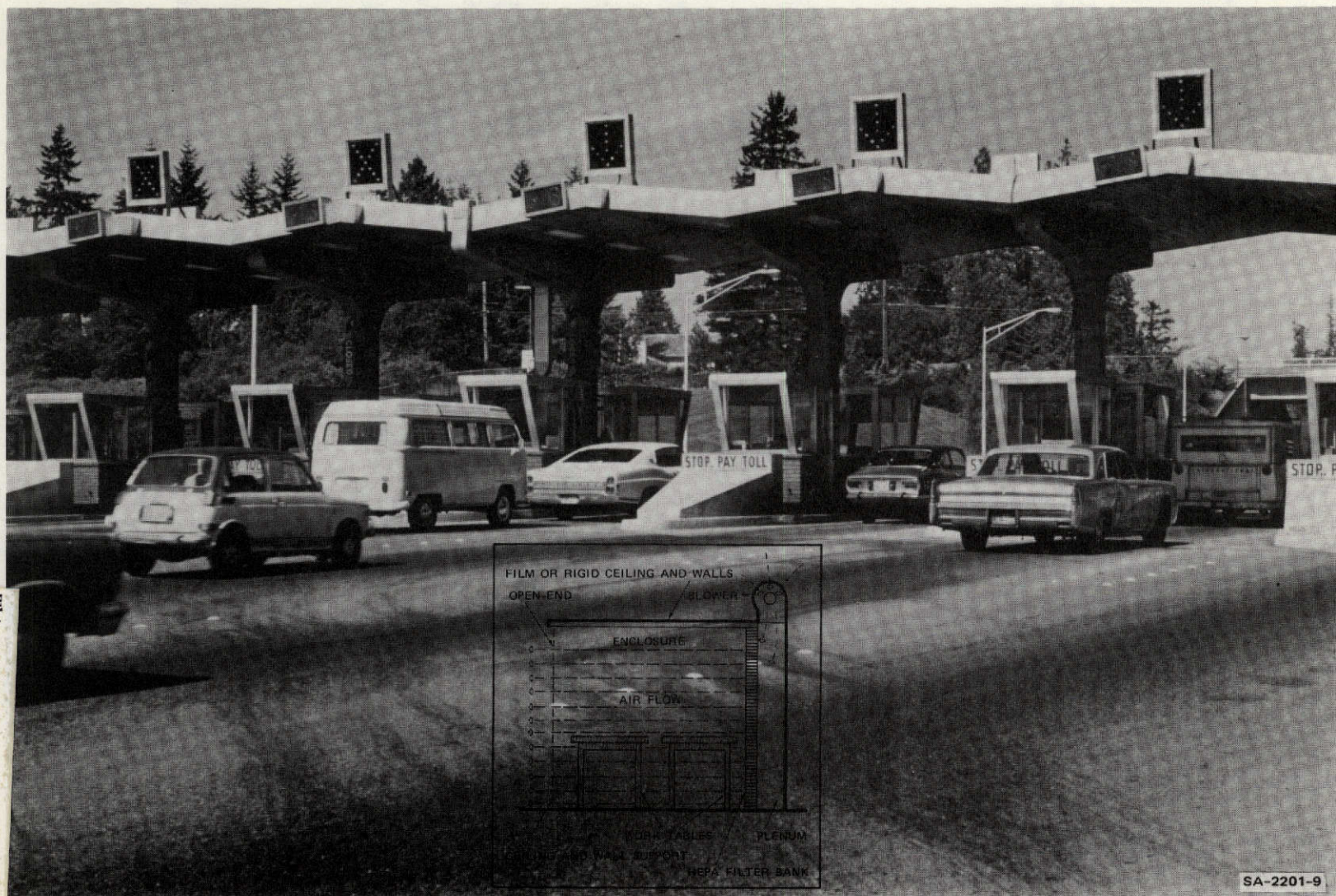
For many years, toll collectors on bridges and turnpikes have been subjected to a health hazard from engine exhaust fumes. Fumes are especially strong at tollbooths because vehicles are decelerating from high speeds and then quickly accelerating again.

To overcome this hazard, the State of Washington decided to include air purifiers in its tollbooth designs. From a search of the data base, the TAT identified three NASA documents on clean room technology, and these documents were forwarded to the Washington engineers. From one of the documents (SP-5045, "Contamination Control Principles"), the engineers found NASA air diffusion technology and laminar air flow designs, which they incorporated in one tollbooth on the Evergreen Point Bridge near Seattle for testing. The tollbooth's laminar air flow design is a combination of the clean air exhaust hood and the laminar air flow tunnel. In the tunnel design, the air is exhausted through an opening (such as a doorway) at the end opposite the diffuser. Air velocity at the opening retards the infiltration of contaminated air. The hood design is added for humidity and temperature control. A blower with a variable flow rate adjusts to remove air from the area at the same rate that air is supplied. The diffusion box filters the air and reduces its velocity. A sketch of the design is superimposed on the tollbooth photograph in Figure 3.

Restoration of Obliterated Serial Numbers

This problem was initiated in 1971 as part of the SRI TAT criminalistics mission. The TAT retained interest in it after the criminalistics program was inactivated because thefts of vehicles and road equipment and the subsequent serial number obliterations are a concern to many areas of transportation.

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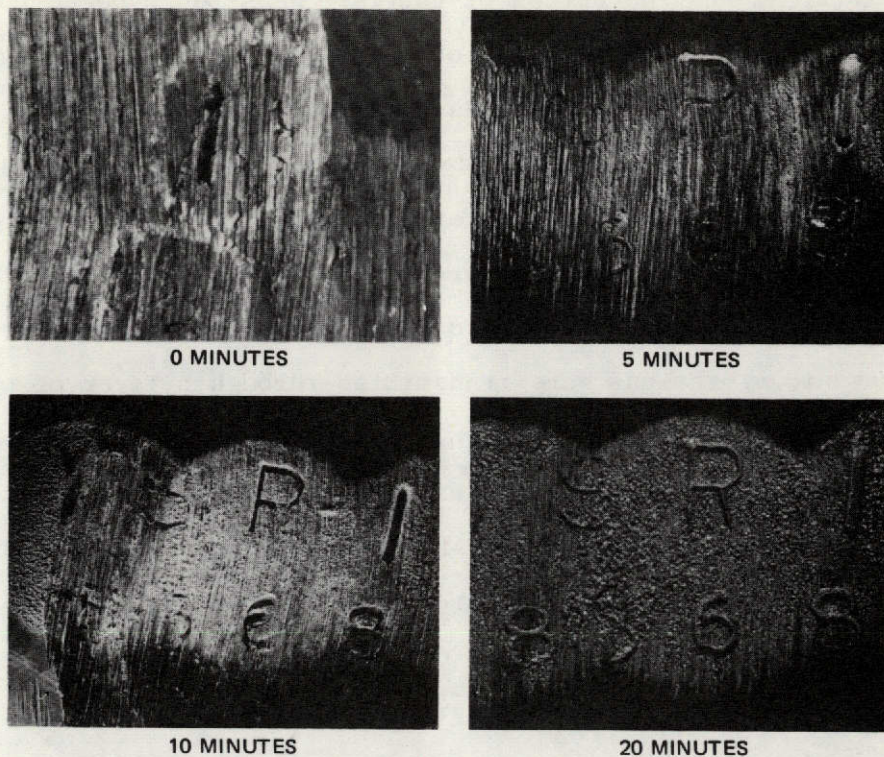
FIGURE 3 NASA CLEAN ROOM TECHNOLOGY ADAPTED FOR AIR PURIFICATION OF TOLLBOOTHS

In 1972, at the suggestion of the TAT, NASA-Lewis began to study the feasibility of a new restoration technique: ultrasonic cavitation. This technique is based on the NASA-Lewis ultrasonic etching of metals (Tech Brief* 71-10099). Specimens of copper, brass, steel, and aluminum were stamped at SRI and then obliterated by grinding. They were taken by the TAT to NASA-Lewis for restoration. Cavitation in water was induced by the ultrasonic vibration of a piezoelectric transducer; that is, ultrasonic vibrations were transmitted through a layer of water to the metal surface. Cavitation bubbles in the excited water produced preferential etching of metal phases or grain boundaries, depending on the relative material properties. Figure 4 shows a schematic drawing of the test apparatus and photomacrographs of a copper specimen after obliteration and at various stages of restoration. Feasibility of this inexpensive technique has been clearly demonstrated and documented. Mr. Young's documentation of this technique (NASA Technical Memorandum TM X-68257) is reprinted in Appendix D. Patent application has been made jointly by the innovator, Mr. Stanley Young, and TAT criminalist, Dr. Brian Parker. The technique was made public in October 1973 when Mr. Young presented his paper to the California Association of Criminalists at its annual meeting at SRI.

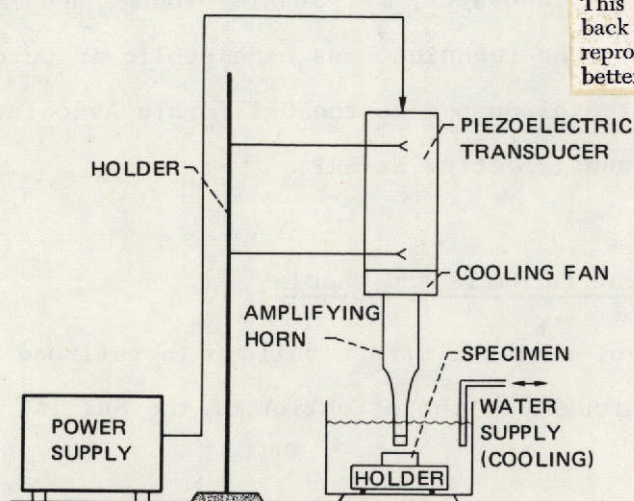
Stress Measurement in Rails and Wheels

The problem of residual stress buildup in railroad track and rail-car wheels was brought to the attention of the SRI TAT by the Federal

* Tech Briefs are short announcements of new technology derived from the research and development activities of NASA. They emphasize information that is likely to be transferrable across industrial, regional, or disciplinary lines and are issued to encourage commercial application.



(a) PHOTOMACROGRAPHS OF COPPER SPECIMEN SUBJECTED TO CAVITATION, SHOWING THE RESTORED LETTERS AND NUMBERS AT VARIOUS EXPOSURE TIMES. -X6.



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(b) SCHEMATIC DIAGRAM OF TEST APPARATUS USED TO RESTORE SERIAL NUMBERS BY ULTRASONICALLY INDUCED CAVITATION.

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FIGURE 4 RESTORATION OF OBLITERATED SERIAL NUMBERS

Railroad Administration. Stresses in track are caused by maintenance work done at different times and at different temperatures; in wheels, they are caused by friction braking.

During a visit to NASA-Marshall, the TAT learned of an ultrasonic technique being developed to detect stress in aluminum. The principal researcher, Mr. Waymon Clotfelter, felt that the approach could be applied to steel. The TAT forwarded the reports to the FRA for evaluation. FRA representatives reviewed the data and agreed that ultrasonics was probably the best solution to the problem, and they inquired about the patent status. They were reassured by the TAT that patent rights could be obtained for commercial use of NASA inventions.

From the NASA concept, a lightweight ultrasonic instrument was designed and fabricated. The instrument was tested for its ability to differentiate between stressed and unstressed steel. Its satisfactory performance reinforced the results of a TAT search of the literature, which indicated that NASA-Marshall's ultrasonic technique was superior to any other known method for measuring stress. The innovator at NASA-Marshall wanted to test the device on tensile and compressive samples of several types of steel, so the AAR provided wheel and rail samples. Although the Marshall researchers encountered some difficulty in handling the high attenuation of the rail steel, they were able to overcome the problem by lowering the test frequency range and redesigning the transducers. Stress increments in the samples were then successfully measured.

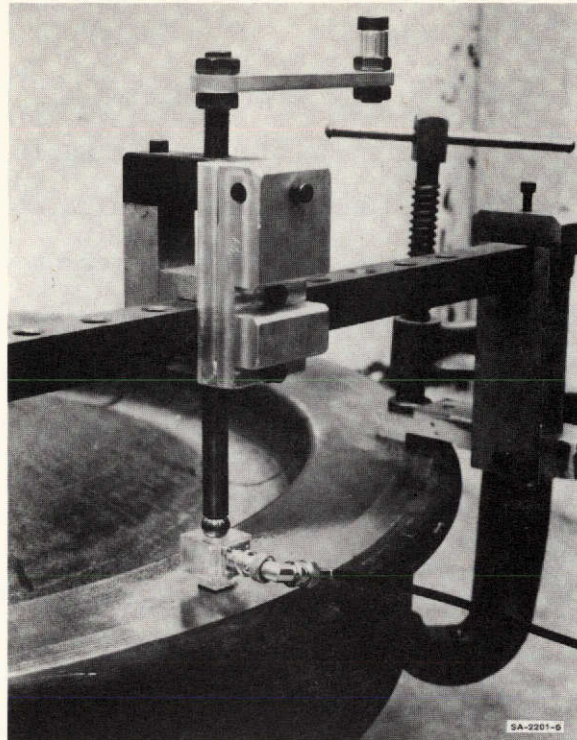
The time now seemed right for a meeting of all parties concerned. Such a meeting was held on March 22, 1972, at NASA-Marshall. A detailed explanation of the theory behind the ultrasonic technique was provided and its feasibility demonstrated on pieces of aluminum and on rail segments. Test results were presented that verified the technique's

capability. The FRA expressed interest in including the technique in its program at U.S. Steel to study the effects of braking on rim stresses, and offered to provide funds.

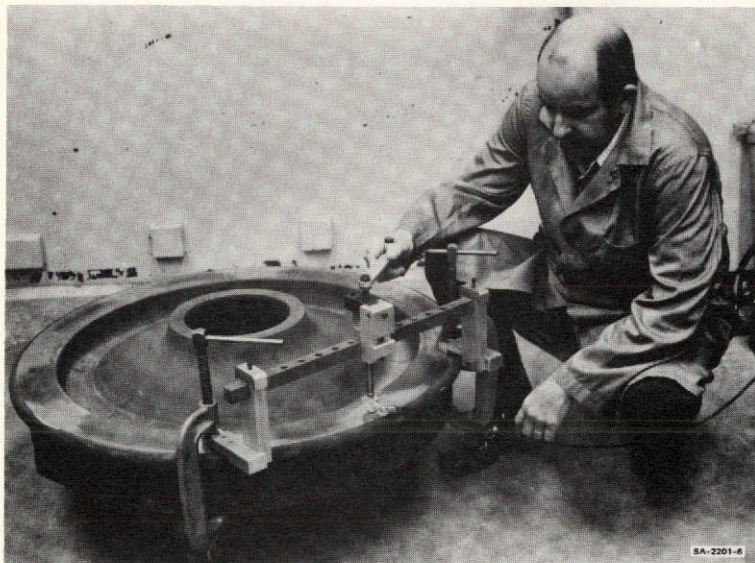
Three different wheels were sent by the FRA to NASA-Marshall and three to Southwest Research Institute. (The FRA had a contract with SwRI to evaluate its magnetic technique.) The wheels were to go back and forth--one each week--until all six had been studied by NASA-Marshall and by SwRI. In preparation for this fast-turnaround study, Marshall researchers obtained a non-test wheel to practice handling procedures, and toured a wheel manufacturing plant to learn more about wheel processing.

The first measurements were made on an FRA wheel in late September (Figure 5). Circumferentially and radially oriented shear wave velocity measurements were made through the rim of each wheel at locations spaced 45° apart. Similar determinations using a 90° change in shear wave polarization were also made. The difference between corresponding radial and circumferential time values were shown to represent stress (in the wheels).

By November, the studies were complete. The measurements showed a decrease in compressive residual stress for older wheels as expected, though no provision had been made for material variability in the wheels. Once the problem of material variability is resolved, firm stress magnitudes can be assigned. With this task accomplished, Marshall researchers were confident that their ultrasonic technique for residual stress measurement was applicable to the railroad use. A final report on the Marshall work is currently in process and will be submitted to the FRA early in 1974.



(a)



(b)

FIGURE 5 APPLYING NASA-MARSHALL TECHNIQUE TO THE MEASUREMENT OF RESIDUAL STRESS IN RAILCAR WHEELS

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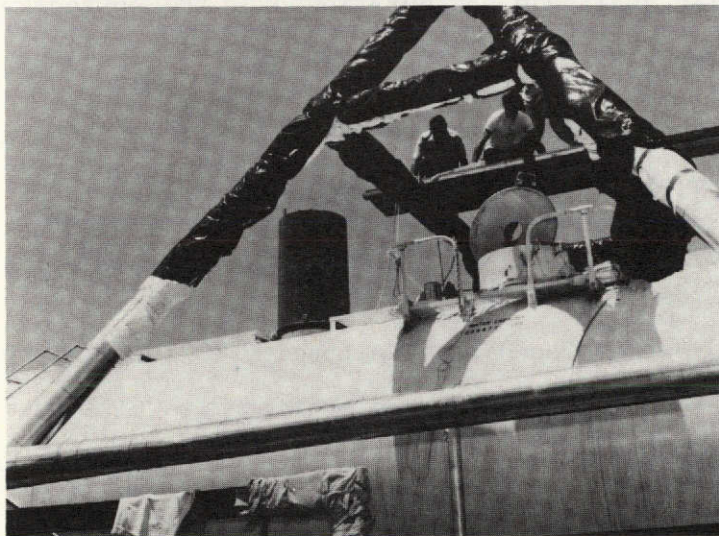
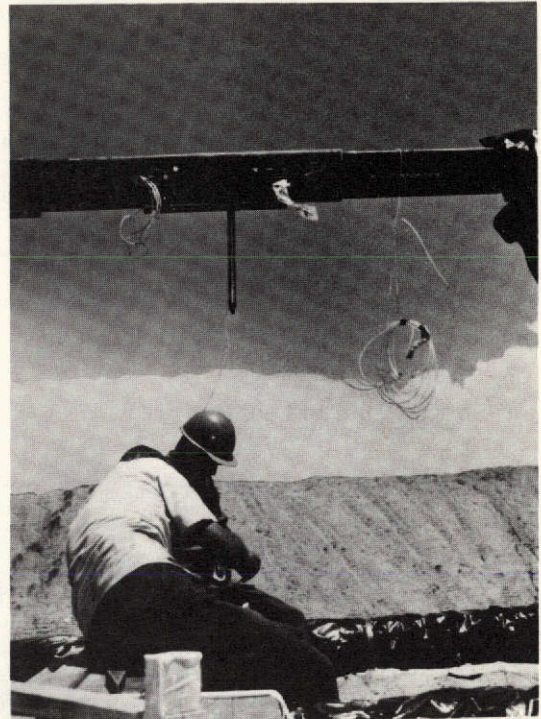
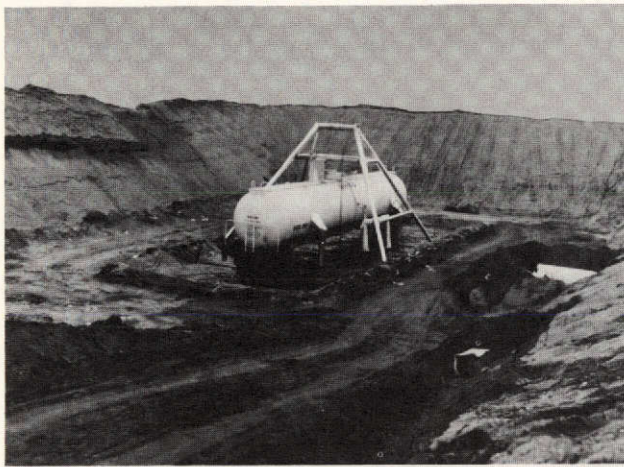
Tank Car Thermal Protection Testing

In the process of screening thermal coating samples for use on railroad tank cars, the Association of American Railroads found that its laboratory fire test could not accurately simulate the tank car fire environment. The fire itself must be better understood. Because NASA-Ames scientists had the expertise to design instrumentation that could provide more realistic data, their assistance was requested in establishing a qualifying test. Funding for this work was promoted by the TAT and provided by the Federal Railroad Administration.

Ames instrumentation, a water-cooled calorimeter, was designed and built. It was included in a 1/5-scale tank car fire test that was conducted at the White Sands Missile Range, Albuquerque, New Mexico, in early 1973. Model tank cars filled with propane were subjected to JP-4 jet fuel fires. The instrument performed very well, giving excellent readings.*

The first full-scale test took place at White Sands on July 28, 1973. TAT member David Merrifield witnessed the burn and also assisted in setting up the Ames instrumentation. Four instruments, including a tank car liquid level gage, the calorimeter, and a thermocouple situated above the pressure valve, were hooked up to a chart recorder. The instrumentation was housed in an A-frame (see Figure 6) which was insulated. The wires were fed through the supports which connected to underground conduits leading to the recorder. The tank car stood upright for this test and was uncoated. As in the 1/5-scale test, the tank car was exposed to the JP-4 jet fuel fire. Evaluation of the NASA data indicates that all the instruments operated very well.

* SRI Semiannual Report, Technology Transfer--Transportation, March 1973, Contract NASw-2455.



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FIGURE 6 NASA-AMES INSTRUMENTATION AT TANK CAR THERMAL PROTECTION TEST

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In the next test, the car will be lying on its side (the usual position following an accident), permitting the liquid cargo to pour from the valve. As in all subsequent tests, the car will be thermally coated.

The researchers at Ames-CRPO* are very enthusiastic about the progress being made on this project. The combined efforts of the AAR, FRA, NASA, and the SRI TAT have resulted in the development of a representative qualifying test procedure for evaluating thermal coatings.

Shock/Vibration Monitor

Loss and damage claims cost the railroad industry about 1% of its return on investment, or \$250 million, annually. The installation of triaxial mechanical recorders that record the time of low-frequency shocks has decreased this expense by identifying the cause of the damage. However, an instrument is needed that can provide sufficient definition of pulse amplitude and duration over the appropriate frequency range to reveal track, train, or packing deficiencies.

A market survey conducted by the SRI TAT confirmed the validity of the problem and the inadequacy of currently available monitors for railroad use. The TAT initiated a technology survey that uncovered three instruments, each partially responsive to the problem. A portable low-frequency system developed at NASA-Langley (B71-10126) would inexpensively, and accurately, record acceleration-time history data, but would operate for only 6 hours. A NASA-Marshall instrument for monitoring transported material through a variety of parameters (B67-10545) would fulfill all the technical requirements but would be prohibitively

* Chemical Research Projects Office

expensive. A triaxial, integrating, vibration amplitude recorder (UCRL 72748) developed by the U.S. Atomic Energy Commission would be small, operate for 2000 hours, require no attendance, and be capable of fast turn-around and easy data readout; however it would not provide a time history. The Association of American Railroads indicated particular interest in the AEC device, and the SRI Team was able to borrow a prototype for road testing. The test runs were successful except for a lack of time correlation. The SRI Team suggested combining the NASA-Langley and AEC monitors or redesigning the AEC instrument. A preliminary economic analysis showed that the projected cost was realistic. The market survey, technology survey, preliminary economic analysis, and modification plan are contained in Appendix C.

In March of 1973, the TAT was contacted by Mr. Jack Arakelian regarding information on the AEC and NASA-Langley monitors. He had seen some of the studies conducted by the SRI Team and was considering commercialization of the combination NASA-AEC model. In June 1973, the TAT learned that Pharos, Inc., of Broomall, Pennsylvania (Mr. Arakelian's company) was building a prototype and preparing for production.

Electro-Explosive Devices for Passenger Restraint Systems

The air bag system, a proposed solution to the Department of Transportation (DoT) requirement for automobile passenger passive restraint capability for 1976 models, may introduce potentially hazardous and operationally unreliable side effects. Inflation of individual air bags will be controlled by a deceleration sensor mounted beneath the front bumper of an automobile. Upon sensing deceleration indicative of a crash mode, the sensor sends a signal to an electro-explosive device (EED) to inflate the bag. A large number of EEDs are planned, an estimated 50-80 million per model year (to provide for replacements,

redundant circuits, and so forth). Inadvertent system initiation and failure to achieve system initiation are significant possibilities. Reliability values of individual explosive components of as high as 0.99999 would still allow a potential for several hundred demand fire or inadvertent actuation failure situations to exist each year.

Work is currently under way at Jet Propulsion Laboratory (JPL) on EEDs similar to those suggested for use in passenger restraint systems. Based on this work, JPL has proposed a program to evaluate and analyze the electro-explosive device ignition aspects of air bag restraint systems. The TAT in coordination with JPL has presented this concept to the DoT and will coordinate future cooperative efforts.

IV PROGRAM VISIBILITY

SRI TAT members participated in six meetings during the report period: the third quarterly review of the Four-Cities Program, the second Street Patching User-Design Committee meeting, the Highway Research Board Sixth Summer Meeting, the Ground Transportation Symposium, the Third Environmental Pollution Symposium, and an American Public Works Association (APWA) Workshop on "Traffic Control Systems."

The Four-Cities review was held in Fresno, California (one of the four cities) on March 15-19, 1973. Representatives of NASA, the National Science Foundation, and the Naval Electronics Laboratory spoke on their respective R&D programs and on technology assessment. A panel composed of the four city managers and their program-appointed science advisors discussed the role of the cities in technology transfer.

Dr. Tom Anyos attended the second Street Patching User-Design Committee meeting, which was held at the Products Research and Chemicals (PRC) facilities in Burbank, California, on March 29, 1973. Representatives of six cities were in attendance: Kalamazoo, Michigan; Burbank, California; Dallas, Texas; Phoenix, Arizona; New Carlyle, Ohio; and Bangor, Maine. Also represented were NASA (Pasadena), the Jet Propulsion Laboratory, E. I. Du Pont de Nemours and Company, Inc., and the Texas Transportation Institute, as well as PTI, PRC, and the SRI TAT. During the PRC presentation, the resilience of NASA's thermoplastic asphalt was demonstrated. This road-patching material was brought to public attention in 1972 by the SRI TAT.* Development of the material

* SRI Semiannual Report, "Transfer of Technology to Selected Public Sector Areas of Concern," Contract NASw-1992, January 1972.

by PRC for street patching continues to look encouraging, and the city representatives appeared eager to road-test it.

The Sixth Summer Meeting of the Highway Research Board, held in Olympia, Washington, on August 6-8, 1973, was attended by Team Director, Dr. Tom Anyos. The theme of the meeting was "Innovations in Construction and Maintenance of Transportation Facilities." The innovations included an electro-osmotic process used by Arizona to stabilize its highly expansive clay soil, a synthetic aggregate made from clay, Germany's bituminous asphalt (gussasphalt) for road surfacing, and a polymer-impregnated concrete for tunnels. A committee meeting on Winter Driving Traction Aids followed the general meeting. Because of his interest in studded tire damage, Dr. Anyos was invited to participate. Several NCHRP (National Cooperative Highway Research Program) projects were reviewed, including "Effects of Studded Tires on Highway Safety." In addition, a progress report was given on Washington's studded tire investigation.

The Ground Transportation Symposium, held on May 31 and June 1, 1973, at the University of Santa Clara, was attended by Mrs. Ruth Lizak. Papers were presented by representatives of academia, industry, transportation consulting firms, and federal, state, and local government. Fixed guideways, bus systems, and intermode transit were discussed from economic, social, environmental, engineering, systems, and esthetic viewpoints. It was concluded that all ground transportation modes--rapid transit, buses, and personal rapid transit--must be made more attractive if they are to lure man from his automobile.

Team members attended several sessions of the Third Environmental Pollution Symposium, which dealt with noise pollution. The symposium was held at SRI on April 18, 1973. Workshops on highway noise and vehicular noise were of particular interest. The TAT gained a better

understanding of noise problems and learned of some of the efforts that have been made to alleviate these problems.

The APWA workshop on "Traffic Control Systems" was held in Los Angeles on January 16-17, 1973. Mrs. Ruth Lizak participated in the discussions, which were concerned with the social, political and technical considerations involved. Leading the discussions were representatives of the FHWA, the Highway Users Federation, the APWA, and consulting agencies, plus several innovative traffic engineers. Of particular interest to the TAT were the technical discussions on large computer-controlled traffic systems and on surveillance systems.

All the meetings were beneficial in acquainting Team members with urgent transportation problems and current attempts to resolve them.

On January 25, 1973, Dr. Tom Anyos presented a paper (see Appendix D) on "Utilization of Waste Glass in Secondary Products" at a symposium sponsored by the Technology Application Center (TAC), the Albuquerque Environmental Health Department, and the Glass Container Manufacturers Institute, Inc. Consideration was given to inclusion of waste glass in paving aggregate, terrazzo, and cement blocks, and to foamed glass and tile, glass wool, and glass polymer composites. Dr. Anyos spoke on the effect of incorporating glass in NASA's thermoplastic road repair material.

The SRI TAT methodology received some publicity in March 1973 when the January/February issue of Technology Mart was published. The article discussed NASA's Technology Utilization Program in general and the SRI Team's method for decreasing the time gap between development and marketing of new technology in particular. The crux of the SRI methodology is the decision point, at which the transfer agent must ask: Is there a problem/market? Is there a potential solution? Is there a real solution (business opportunity)? The entire article is reprinted in Appendix D.

V CONCLUSIONS

During the past year, the SRI TAT has continued to increase its competence and capabilities in the transfer of aerospace technology to the public sector of transportation. Six projects started in FY '72 reached the transfer stage, and a number of new projects were initiated. The methodology for transferring technology was continually refined to be more effective, and techniques were developed for shortening the time between problem identification and transfer of NASA technology. Greater awareness of the role of the private sector and the need for its involvement in the transfer process has led to the development of new techniques designed to draw private sector agencies into the process.

The Team has continued to expand its scope and increase public awareness of the NASA TU effort. It has devised and implemented techniques to achieve the broadest coverage and recognition in five areas of transportation: highways, railroads, rapid transit, mass transit, and waterways.

Transfers resulting from SRI TAT activity are:

The Need	The NASA Solution
An objective method of testing driver coordination.	LRC's Complex Coordinator (B70-10619*) for training astronauts.
A technique for nondestructively measuring the thickness of Portland cement concrete.	MSFC's Eddy Current Proximity Gage (B68-10183*) for detecting metal.

* NASA Tech Brief designation.

The Need	The NASA Solution
Nondestructive inspection of bridges.	ARC's Randomdec technique (B71-10284*) for testing the structural integrity of airplanes.
An improved road-patching material.	JPL's Thermoplastic Material (B66-10453*) for binding rocket propellants.
An improved friction material for railcar and postal vehicle brake linings.	ARC's Polyphenylene Polymer, developed for SST brakes.
Air purification of tollbooths.	NASA Air Diffuser (SP-5045, N66-11215*) for clean-room application.
Restoration of obliterated serial numbers.	LeRC Ultrasonic Cavitation (TB71-10099*) for etching metals.
Stress measurement in rails and railcar wheels.	MSFC Ultrasonics (B67-10428*).
Tank car thermal protection testing.	ARC Instrumentation for Tank Car Burn.
Track/train dynamics.	MSFC Telemetry Assistance.

* NASA Tech Brief designation.

Appendix A
PUBLIC SECTOR AGENCIES

PUBLIC SECTOR AGENCIES

Alaska Department of Highways,
Juneau, Alaska

Alaska Department of Public Works,
Juneau, Alaska

Alviso Economic Development Agency,
Alviso, California

Asphalt Institute,
Oakland, California

Association of American Railroads,
Washington, D.C. and Chicago, Illinois

Burlington Northern, Inc.,
St. Paul, Minnesota

California Department of Justice,
Sacramento, California

California Department of Transportation,
Sacramento, California

De Young Memorial Museum,
San Francisco, California

Federal Highway Administration,
Washington, D.C.

Federal Railroad Administration,
Washington, D.C.

Florida Department of Transportation,
Tallahassee, Florida

Georgia Department of Transportation,
Atlanta, Georgia

Glass Container Manufacturers Institute,
Washington, D.C.

Institute for Rapid Transit,
Washington, D.C.

Kentucky Department of Highways,
Frankfort, Kentucky

Maryland Department of Transportation,
Brooklandville, Maryland

National Association of Home Builders
Research Foundation, Inc.,
Rockville, Maryland

National Association of Motor Bus
Operators,
Washington, D.C.

National Highway Traffic Safety
Administration,
Washington, D.C.

National Science Foundation,
Washington, D.C.

Ohio Highway Testing Laboratory,
Columbus, Ohio

Ohio Highway Transportation Research
Center,
Columbus, Ohio

Pennsylvania Department of Transportation,
Harrisburg, Pennsylvania

San Jose Department of Public Works,
San Jose, California

Santa Clara County District Attorney's
Office,
San Jose, California

Southern Pacific Transportation Company,
San Francisco, California

Transit Development Corporation, Inc.,
Washington, D.C.

U.S. Department of Transportation,
Washington, D.C.

U.S. Postal Service,
Washington, D.C. and Rockville,
Maryland

Urban Mass Transportation Administration,
Washington, D.C.

Washington Department of Highways,
Olympia, Washington

Appendix B
CURRENT PROBLEMS, PROJECTS, AND TRANSFERS

CURRENT PROBLEMS, PROJECTS, AND TRANSFERS

HIGHWAYS

***H-2 Pavement Thickness Measurement:** In both newly laid and older Portland cement concrete pavements, it is necessary to determine the thickness with some degree of accuracy. For new pavement, measurement is necessary to ensure that construction specifications have been met. For older pavement, load carrying capabilities must be assessed. Because of the miles of highway to be tested and the close spacing of the tests, a rapid, inexpensive method is needed--preferably a nondestructive one.

A battery-operating device was developed at Marshall Space Flight Center. Similar to a metal detector, it can detect a metal plate or foil laid on the base course before paving.

The device was successfully tested in Pennsylvania and Louisiana. A final design has now been approved for marketing, and South Eastern Associates of Huntsville, Alabama is beginning production.

The TAT has cooperated with the manufacturer by arranging for highway demonstrations in several western states.

****H-3 Pavement Texture Measurement:** Highway-accident researchers have identified significant relationships between road surface texture characteristics and skid-related accident rates. As a result, the Federal Highway Safety Act of 1966 provided for "pavement design and construction with specific provisions for high skid-resistance qualities" and "resurfacing or other surface treatment...of streets and highways with low skid resistance...." The surface texture of highway pavements must be measured to determine skid potential. The test device (preferably an electronic instrument) should be operable at maximum highway speeds.

A project has been initiated at NASA-Marshall to build a stable platform prototype which will measure roll, pitch, and yaw with reference to inertial space as well as acceleration. The platform will be tested by the California Division of Highways.

* Transfer Phase

** Project Phase

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H-4 Pavement Compressive Strength Measurement: The strength of a given concrete varies with a number of factors, the more important being compressive strength of the cement paste and gradation and strength of the aggregates, the mix proportions, the water-cement ratio, and the curing methods. Several standardized tests have been developed by the American Society for Testing and Materials; however, these tests are limited to individual concrete mix components or to laboratory or job mix samples in an environment differing drastically from the finished pavement.

A rapid, inexpensive, and accurate method is needed to measure the structural strength of the finished pavement.

*H-5 Bridge Failure Detection: Technology is sought to enhance bridge inspection capability. There are approximately 500,000 bridges on U.S. highways, and no definitive method exists for determining which ones may be in jeopardy due to cracks not detectable by routine visual inspection. The SRI Team learned of a NASA-Ames technique, called Randomdec, that monitors the structure's random vibration signatures. It uses accelerometers as sensors, which feed into a correlation computer. A joint NASA/FHWA project (involving an interagency transfer of funds from FHWA to NASA) is being undertaken by the innovators to evaluate the technique in laboratory and field tests. The program will now be administered by NASA-Ames, with the SRI TAT moving into the follow-on stages.

*H-6 Road Repair Material: Highway maintenance crews desired a strong patching material that could be applied and set between rush hours, when closing a lane would not impede the flow of traffic. A thermoplastic material that was developed at NASA's Jet Propulsion Laboratory as a rocket propellant binder appeared to fill this need. A formulation of the material, with a safe-handling melting point, was mixed with aggregate and applied by the California Division of Highways to the deceleration lane of California Highway 99 at Florin Road. After several months, the test strip that had been applied with heated aggregate had 100% aggregate retention. The material has been suggested by the CDH for inclusion in the National Cooperative Highway Research Program's tests.

Representatives of the SRI TAT and Public Technology, Inc. (PTI) visited a chemical company in southern California, Products Research

*
Transfer Phase

and Chemicals Corporation (PRC), to discuss commercialization of the thermoplastic material. A cooperative effort was initiated by PTI and the producer, with SRI moving into the follow-on stages.

*H-8 Improved Friction Material: New materials for brake linings are greatly needed for increased wear and safety. The Postal Service is anxious to increase the time between relinings for postal vehicles. The Postal Service, the railroad industry, and others are interested in a brake lining that does not contain asbestos, a material suspected of being a public health hazard. An improved material was found at NASA-Ames in a reformulated airplane friction material developed for SST brakes. A production economics study made at SRI indicated that the new composition can be produced at a reasonable cost. Therefore, an adaptive engineering program was undertaken at Ames to modify the material for postal vehicle use. Brake linings are currently being fabricated at Bendix Corporation from the Ames material.

**H-9 Electric Vehicle: The Postal Service is considering electric vehicles for mail delivery. Although long-range plans include a fuel cell concept for supplying power, an improved battery would provide a good short-range solution. Currently available lead-acid batteries supply 10 to 15 watt-hr/lb, whereas at least 30 watt-hr/lb are necessary to accelerate from 0 to 45 mph in 45 seconds during transit and from 0 to 10 mph in 3 seconds during mail delivery. As many as 130 stops may be required on one route, 35% on uphill grades. To take full advantage of battery improvements, a more efficient electric motor is also being sought, one requiring little maintenance.

Work is under way at NASA-Lewis to design a high performance battery which in laboratory tests on small cells is achieving very close to 30 watt-hr/lb.

H-10 Subsurface Moisture Measurement: The negative relationship between the presence of water and the service life of a pavement has been recognized for a long time by highway engineers. Efforts to remove subsurface moisture have been hampered, however, by the lack of accurate instruments or techniques for measuring moisture. Instrumentation is desired that can be implanted in pavement or subgrade

* Transfer Phase
** Project Phase

and can provide a readout of local moisture content on demand. The device should be long lasting, small, durable, and inexpensive because many may be needed in suspect areas.

H-11 Examination of Sinkhole-Prone Areas: In addition to the usual structural inspection of bridges, Florida will be required to test the foundations for sinkholes. Since almost all of Florida's 5000 highway bridges are located in areas prone to sinkholes, an inspection method is desired requiring little or no drilling, which is time-consuming.

Interest has been expressed by Florida and several other southeastern states in NASA's swept-frequency UHF radiometer (B70-10617) developed for probing the lunar surface. Plans are being made for initiating a feasibility study.

H-12 Road Marker Evaluation: In conjunction with the Federally Coordinated Program of Research and Development in Highway Transportation, a rapid, reliable instrument is needed to evaluate the night visibility of road markers quantitatively. Today's highway speeds demand that road markers be visible for greater distances, particularly those markers denoting curves, merging lanes, and so forth, and subjective evaluations are no longer adequate. The instrument should be operable at night from a moving vehicle.

H-15 Bridge Corrosion: Because of their exposure to salt spray, coastal bridges require more corrosion protection than is needed inland. Currently available zinc coatings provide only a few years of coastal protection, whereas coatings on inland bridges provide protection over a fifteen-year period.

*H-16 Air Purification for Tollbooths: An economically feasible system is needed for providing purified air to tollbooths. The high concentration of vehicle exhaust compounds in the tollbooth area is thought to be a health hazard.

H-17 Restoration of Obliterated Serial Numbers: Serial numbers stamped in motor blocks are often filed in an attempt to change the identification. A means of retrieving the original numbers was developed at NASA-Lewis by ultrasonically induced cavitation (B71-10099).

* Transfer Stage

Specimens of copper, brass, steel, and aluminum were stamped at SRI and then obliterated by grinding. At NASA-Lewis, cavitation in water was induced by the ultrasonic vibration of a piezoelectric transducer. The numbers were restored and the restoration documented in NASA TM-X-68257.

H-18 Dynamic Peak Force of Bridge Pilings: Bridge piling integrity is determined by impacting a hammer to the structure. The resulting dynamic peak force must be recorded and analyzed; however, no instrument is currently available to record these data.

RAILWAYS

R-1 Roller Bearing Failure Detection: The railroad industry is currently changing over from journal bearings to roller bearings, which give better service. Journal bearings are monitored for impending failure by bolometers, which compare the temperatures of bearings on either side of the axle. This method is not effective for roller bearings, however, because they do not exhibit the long temperature rise before failure that is characteristic of journal bearings. Thus, in considering methods of detecting failure of roller bearings, it may be necessary to monitor parameters other than temperature. The monitor should provide a positive indication of impending failure. An onboard system is preferred.

*R-2 Stress Measurement in Rails and Wheels: Detection of locked-in stresses is essential in preventing derailments. In rails, these stresses are caused by maintenance work done at different times and at different temperatures; in wheels, they are caused by friction braking. NASA-Marshall has developed ultrasonic techniques for measuring stress conditions near welds in large assemblies. The SRI Team arranged a meeting at Marshall to demonstrate the feasibility of applying these techniques to the measurement of stress in rail and wheel rim segments. The segments were supplied by the Association of American Railroads. Feasibility was successfully demonstrated, and additional work at Marshall was funded by the Federal Railroad Administration.

* Transfer Phase

Ultrasonic velocity measurements were made on assorted wheel segments, calibration blocks and five wheels. Repeated measurements on a given sample were very consistent; however, considerable material variability was found. Stress change measurements may be possible by measuring the initial conditions of wheels as a reference for future measurements. Development of a method to evaluate material variability would eliminate the need for such a procedure.

*R-3 Shock/Vibration Monitor: Claims for freight damage cost the nation's railroads about a quarter of a billion dollars annually. With a better knowledge of the actual freight environment, the industry could prevent freight damage and reduce damage claims. The railroads need an inexpensive ($\sim \$1000$), portable, time referenced, three-axis shock/vibration monitor that can sense 0 to 50 g, 0 to 200 cps loads, record essential statistics, and operate unattended for up to eight days. In addition, it must be possible for nontechnical personnel to read out and reset the recorder.

A Technology Survey yielded a NASA-Langley vibration recorder (B71-10126) and an AEC shock/vibration monitor (UCRL-72748) that meet these requirements. A Market Survey indicated that the units, if properly priced, could have a competitive advantage over related products now being sold. A Preliminary Economic Analysis indicated that the unit would be produced for about \$1000--certainly a competitive price. These reports plus design details were given to a Pennsylvania manufacturer which is currently preparing to fabricate a device that combines the AEC design with a design developed at NASA-Langley.

*R-4 Thermal Coating for Tank Cars: The railroad industry is studying ways to prevent catastrophic failures of tank cars in post-derailment environments. Fire retardant or protective coatings are being evaluated for their ability to maintain 5/8-inch-steel tank cars at 800° or below for 1/2 to 4 hours during a fire. The SRI Team found a potential candidate material in a fiber-loaded intumescent coating developed at NASA-Ames. Over forty samples, including the Ames material, were evaluated by the Association of American Railroads. The Ames coating was one of several meeting the time-temperature specifications for strength, weatherability, and ease of application. Its cost was the main drawback to the material's acceptance. Therefore, the formulation was modified to

* Transfer Phase

reduce the cost. In addition an outer coating to allow color variation was developed at the Naval Air Development Center of Johnsville, Pennsylvania, in cooperation with NASA-Ames. The foam is now being produced commercially.

*R-5 Tank Car Thermal Protection Testing: NASA-Ames researchers working on thermal coatings for tank cars pointed out differences between the AAR/RPI fire test and other laboratory tests for simulating large pool fires. This led to a request by AAR/RPI for assistance from NASA in simulating a full-scale tank car fire and developing a suitable laboratory qualifying test procedure for candidate coatings. A proposal for a program to establish a qualifying procedure was submitted by the Chemical Research Projects Office at Ames and was approved by the AAR/RPI and the SRI Team. It has been funded by the Federal Railroad Administration. The test program is currently under way. Instrumented tank cars are subjected to actual fuel fires.

*R-6 Track/Train Dynamics Projects: The Association of American Railroads is embarking on a national research program to investigate Track/Train Dynamics. The program is expected to lead to improved operating procedures and equipment design. The AAR and the Federal Railroad Administration, a partial sponsor of the program, wish to benefit from some of NASA's unique technology and capability in data acquisition and analysis, instrument development, and dynamic modeling. Therefore, NASA-Marshall assistance on the program has been contracted.

R-10 Railcar Component Screening: The Federal Railroad Administration recently proposed its first safety standards for freight cars, to cover correction of such defects as faulty suspension systems, loose wheels, broken axles, and worn couplers. To comply with these standards, the railroads must develop inspection systems to detect bad components. A rapid method of screening railcars is being sought.

R-11 Defective Railcar Wheel Detection: Some 100 derailments annually are attributed to the failure of railcar wheels, and the loadings. No routine procedure exists for spotting defective wheels. Any method, preferably located at trackside, would have to be sensitive to cracks in the wheel flange, rim, plate, and hub.

* Transfer Phase

R-12 Air Brake Hose: Burst air-brake hoses cause too many railroad delays. When a freight train is formed, each railcar air brake system is joined to the systems of adjacent cars by air brake hose couplings, and the entire braking system is pressurized to 90 psi. A failsafe system causes each car's brakes to be automatically applied whenever a certain reduction in pressure occurs. Because burst hoses cause pressure drops which stop trains, improved hoses are being sought.

R-13 dc Motors: An untold number of transit cars operate in the United States, and the dc motor is the main propulsion unit on many of them. In New York City alone, 30,000 motors are in operation daily. Frequent maintenance and replacement of these motors are required, however, due to arcing, flashovers, burnups, and dc commutation problems. Better motors are needed to reduce maintenance costs.

R-14 High-Temperature Lubricants: Two aspects of the lubricant problem are recognized: performance under thermal conditions and resistance to fire. Railroad and rapid transit agencies are considering both aspects, and are also investigating test methods. At the AAR, an ad hoc committee has been formed to conduct the investigation.

URBAN MASS TRANSIT

U-1 Shatterproof Windows: From the standpoint of maintenance and repair, bus windows are a major concern of bus operators. Broken windows from rocks thrown at passing buses and from road debris represent both a safety hazard and an economic burden to the bus operator. The need for shatterproof, optically clear materials for use in bus windows has therefore been demonstrated. Although materials are currently available that claim to meet this need, none has proven totally acceptable.

Appendix C
TECHNOECONOMIC STUDIES

SHOCK/VIBRATION MONITOR

Market Survey

Four companies were identified as producers of equipment capable of monitoring and recording the triaxial shock and vibration in a transportation environment. The product lines of these companies are listed below, together with the company name, appropriate selling price, and physical specifications of each product.

Product	Company	Cost	Operating Life	Dimensions (in.)	Weight (lb)
Impact-O-Graph	Torq Engineered Products	\$ 545	21 days (clock)	12 x 11 x 5	12
RM Three-Way Accelerometer	Impact Register	960	30 days (clock)	10 x 7 x 6	14
G Environmental Mini Monitor (GEMM)	Impact Register	540	30 days (clock)	8 x 4 x 3	4
Acceleration Monitoring System	Schaevitz Engineering	6,500	6 hours (battery)	12 x 14 x 9	30
Transportation Environmental Measuring and Recording System (TEMARS)	Endevco	12,500	40 hours (battery) 10 days (external battery)	19 x 18 x 17	55 80

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The five product lines listed were identified by surveying twenty companies that appeared to be active in this field (see page 50). The TAT considered only those triaxial instruments that were specifically directed toward the transportation market and that combined the monitoring and recording functions.

The first three products can be classified as mechanical recording accelerometers. They provide a 30-day record of peak acceleration as a function of time on a paper chart that moves past the recording head at 1/2 inch/hour. The units are completely self-contained and can be completely mechanical. The chart drive is typically a spring-wound clock. However, battery-driven clocks and motors are also available for more rapid chart movement. The acceleration sensing transducers are damped mass-spring systems, which can be specified for full-scale ratings from 1 g to over 100 g. The natural frequency of these systems at low g levels is about 10 cps. This sets the maximum frequency to which these systems will respond.

For these three product lines with various options and attachments, the unit price range is approximately \$500 to \$1000. At these prices, the instruments are useful when time of occurrence and relative severity of shocks are of interest. However, the chart speeds are too slow to determine pulse shapes and frequencies, and the nature of the mass-spring transducer limits the frequency range over which meaningful results are produced.

The fourth product overcomes the frequency limitations. Servo accelerometers, having a natural frequency of about 100 cps at low g levels, are used in this system. This frequency range covers most ground transportation environments. This system does not produce acceleration-versus-time histories, but counts the number of times five different preset \pm g levels are exceeded. Because of its greater range of

frequency response, the system provides a more accurate picture of the shock/vibration environment that may have caused damage; however, it cannot pinpoint the time that the damage occurred. In addition, the high unit cost of \$6,500 and the six-hour battery life severely limit the usefulness of this device.

The Endevco product overcomes all the disadvantages of the first four products. It employs piezoelectric accelerometers to cover the entire meaningful frequency range and a digital tape recorder to record pulse amplitude, polarity, duration, and time of occurrence. In addition, it provides time-correlated temperature, humidity, and barometric pressure data. A low g filter on each channel reduces the amount of unwanted data. Computer programs are available to process and report the data in easily interpretable form. This unit performs all the functions that are desired in this type of instrumentation; however, its high unit price of \$12,500 and its operating complexity are major drawbacks to its usefulness.

On the basis of dollar sales of these five companies, it is estimated that the annual unit sales of the three mechanical recording accelerometers are between 200 and 1000 units. In the future it appears that the GEMM (Impact Register, Inc.) and the Impact-O-Graph (Torq Engineered Products) instruments will control this segment of the market with annual sales approaching 1000 units at a cost approaching \$600/unit.

Only a few of the newly introduced Scheavitz instruments have been sold. Because of limited performance capability and high cost, their future impact on the market is expected to be negligible. Perhaps a few dozen of the TEMARS instruments have been sold over the last few years. While the TEMARS lacks nothing in performance, its extremely high cost will continue to inhibit wider market acceptance.

This survey indicates that there is a place in the market for a rugged, compact, easy to operate shock/vibration measuring and recording instrument with better performance than the mechanical recording accelerometers. Such an instrument, priced at about \$1,000, could be expected to achieve wide acceptance.

The twenty companies surveyed are listed below.

Barber-Colman Company Hoboken, New Jersey 07030	L.A.B. Corporation Skaneateles, New York 13152
Columbia Research Laboratories Woodlyn, Pennsylvania 19094	Mantec, Inc. El Segundo, California 90245
Endevco Pasadena, California 91109	Metrix Instrument Company Houston, Texas 77032
The Foxboro Company Cleveland, Ohio 02035	Noremac Instrument Corporation Buffalo, New York 14202
Gaynes Engineering Company Chicago, Illinois 60612	Precision Instrument Company Nyack, New York 10960
General Electric Company Schenectady, New York 12305	Remtach, Inc. Santa Ana, California 92705
General Precision Systems Little Falls, New Jersey 07424	Schaevitz Engineering Camden, New Jersey 08101
Impact-O-Graph Corporation Cleveland, Ohio 44114	Setra Systems, Inc. Natick, Massachusetts 01760
Jan Hardware Manufacturing Company, Inc. Long Island City, New York 11101	Testing Machines, Inc. Amityville, New York 11701
	Vexilar Engineering, Inc. Minneapolis, Minnesota 55404

Technology Survey

A computer search strategy, which was devised by the SRI TAT and NASA-STIF, (Scientific and Technical Information Facility), produced three kinds of useful information.

- (1) Numerous reports were found that defined shock and vibration conditions in various modes of transportation. Methods of testing to meet specific shock and vibration specifications were covered in other reports, some of which were forwarded to the user.
- (2) A few citations were found describing instrumentation dealing with only part of the problem (e.g., improved acceleration measuring concepts or unique methods for recording data). This information was not of interest to the user.
- (3) One citation (TB71-10126, "Portable Low-Frequency Vibration Measuring and Recording System") was responsive to the problem statement.

A manual search of the Tech Brief Index revealed the same citation given above and one other (TB67-10545, "Instrumentation Monitors Transported Material through Variety of Parameters"). In addition, WESRAC (Western Research Application Center, Los Angeles) brought to our attention a report on an AEC system (UCRL 72748, "A Triaxial Bidirectional Integrating 4-Level Acceleration Amplitude Recorder"). All three reports describe instruments that are reasonably responsive to the problem statement. The instruments measure and record triaxial shock and vibration data and are capable of covering the appropriate g range and frequency range. However, each instrument has its own individual drawbacks.

The NASA-Langley instrument (TB71-10126) employs a home tape recorder for inexpensively, but accurately, recording acceleration-time history data. This limits the operating life of the system to 6 hours, a fraction of the 8-day requirement. In addition, the system must be

attended by a skilled person, and the data playback and analysis is a lengthy process. Because it records complete acceleration-time histories inexpensively, the Langley instrument may be useful in the railroad industry's national research program on track/train dynamics.

The NASA-Marshall device (TB67-10545) proved to be the forerunner of the commercially available TEMARS instrument discussed in the market survey. Although fully responsive to the technical requirements of the problem statement, this instrument has not been put into general use by the railroad industry because of its prohibitive cost.

The principal drawback of the AEC device (UCRL 72748) seems to be its lack of a time correlation capability. If this is a limiting consideration, redesign may be possible. The user is enthusiastic about the instrument. The instrument is completely housed in a 6-inch cube, has only one switch (on-off), and has a 2000-hr battery life. In addition, the data can be read out and analyzed quickly. The SRI TAT believes this technology may solve the problem. In addition to meeting most of the technical requirements, it shows promise of falling in a suitable price range, as determined in the market survey.

Preliminary Economic Analysis

Mr. C. Bruce Clark of SRI's Engineering Sciences Laboratory has estimated the cost of producing a three-axis shock/vibration monitor. The following costs apply to production of quantities of 1000 units in a single production run. The major cost items follow.

<u>Description</u>		<u>Unit</u> <u>Cost</u>	<u>Number</u> <u>Required</u>	<u>Line</u> <u>Cost</u>
Accelerometer	Endevco - 2215E	\$110	3	\$330
"E" Cell	Plessey - 500	1	31	31
Op Amp	Zeltex - 170	11	3	33
Electronic parts	-	43	3	129*
Power card	-	10	1	10
PC cards	-	8	3	24
Metal box	-	20	1	20
PC connectors	AMP	2	4	8
Accel. cables and connector	-	4	3	12
				<u>\$597</u>
Assembly and checkout				<u>50</u>
Total				\$647

The total cost of \$647 does not include factory overhead or profit. In this quantity, Mr. Clark estimates that the units could be sold for about \$1000 each, based on the present design.

If redesign were allowed, the accelerometer cost could be reduced from \$110 to about \$50 per axis according to Endevco. A single three-axis accelerometer would be used that would include a preamplifier so that the electronic circuitry would be somewhat simplified. If it were acceptable to mount the accelerometer in the same box as the electronics, cables and connectors could be avoided, allowing a further reduction of about \$12 per unit. These minor changes in the design would reduce the purchase price to about \$750 assuming that only 1000 units were needed.

* See breakdown in page 54.

If very large quantities were needed (over 10,000 units), a complete redesign would be justified, and Mr. Clark estimates that the overall cost could be reduced to about \$500. Note that the dominating cost is still the cost of the accelerometers and that further reductions could be made here. It is possible that the cost could be reduced much further if the specifications were eased.

A breakdown of the costs for electronic parts is given below.

<u>Description</u>	<u>Unit Cost</u>	<u>Quantity</u>	<u>Line Cost</u>
Capacitor, 330 pf	\$0.10	1	\$ 0.10
Tant cap, 39 μ f	0.43	2	0.86
Ceramic cap, 1 μ f	0.78	3	2.34
Ceramic cap, 0.001 μ f	0.40	1	0.40
Diode (constant I) for 5283	2.95	8	23.60
Diode, for 4148	0.22	10	2.20
Diode, 5082-2800 hp	0.75	4	3.00
Resistor, RX-1 Victoreen	1.00	1	1.00
Resistors, carbon (misc.)	0.04	17	0.68
Resistor (var), Bournes	2.50	2	5.00
UJT, General Electric	0.40	2	0.80
Transistor, 2N 2608	2.80	1	<u>2.80</u>
Line cost per axis			\$ 42.78
			<u>x 3</u>
Total electronic parts cost			\$ 129.00

Modification Plan

A shock/vibration monitor that is suitable for recording freight environments can be realized by modifying the LRC recorder to cover longer periods of time or by adding real time to the AEC monitor.

A modification plan, devised at SRI, would add time recording to the AEC monitor with a precision of ± 1 minute. A time word would be recorded every hour so that no ambiguity would result from irregular time records. Two to three records per hour (500 records over the 200-hour period) should be sufficient. A record would be made each time the acceleration threshold was exceeded, except that a maximum of about 10 records per hour would be allowed. This would conserve the memory capacity of the device so that it would not be used up by frequent events early in the journey.

Another strategy would be to allow recording of high shock events on a different basis from those just exceeding threshold. Time would be recorded every hour to ensure that no ambiguity existed and that the equipment was operating normally. In addition, the least significant bits of the time word would be recorded whenever an event occurred that exceeded a current acceleration threshold. Four bits would be allowed for the type of event. Thus, 12 bits would be recorded each time: 6 bits for the least significant bit part of the time word, 4 bits for marker, and 1 bit for parity. Four 2000-bit shift registers would be used to record the time and type of information. These registers would be used in sequence as the journey progressed.

Being aware of the interest of Pharos, Inc., in manufacturing a shock/vibration monitor for railroad use, the TAT was pleased to provide a file of technical and economic information, as outlined on pages 47 through 55. The prototype monitor that Pharos, Inc., is currently building contains some features of the AEC monitor and some features of the NASA-Langley recorder, which has been modified to cover longer time periods. The resulting instrument appears to meet all the railroad specifications.

Appendix D
PRESENTATIONS AND PUBLICATIONS

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Paper presented
at the
Albuquerque Symposium
on "Utilization of Waste Glass in Secondary Products"
January 24-25, 1973

A NOVEL THERMOPLASTIC PAVING MATERIAL

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Abstract

Stanford Research Institute's Technology Applications Team, under contract to NASA, is concerned with transferring aerospace technology to the public sector. In the area of transportation, the Team became aware of several universal needs related to improved road patching materials, better corrosion protection of bridge structural members, and less expensive oil- and gasoline-resistant paving materials for special purposes. A potential answer to these needs was found in NASA Tech Brief B66-10453, "A Thermoplastic Rubberlike Material." Additional work was performed at SRI to evaluate the basic properties of the thermoplastic material, the effects of various fillers such as glass on these properties, the methods of applications, and the potential commercial uses for the material.

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Introduction

Stanford Research Institute has a Technology Applications Team under contract to the Technology Utilization Office of the National Aeronautics and Space Administration. This Team is concerned with the transfer of aerospace technology to the public sector area of transportation. In the course of its activities, the Team became aware of several universal needs related to improved road patching material, better corrosion protection of bridge structural members, and less expensive oil- and gasoline-resistant paving materials for special purposes.

A search of the aerospace data base uncovered a potential answer to these needs in NASA Tech Brief B66-10453, "A Thermoplastic Rubberlike Material," (subsequently U.S. Patent No. 3,527,724). The work was originally performed for NASA to develop new binder systems for rocket propellants.

This paper discusses additional work performed at SRI to evaluate the basic properties of the thermoplastic material, the effects of various fillers on these properties, the methods of applications, and the potential commercial uses for the material.

Experimental

The basic formulation is prepared by blending a copolymer of ethylene and vinyl acetate with asphalt and a petroleum distillate. For testing purposes, Examples 1 and 3 of the patent were reproduced. The asphalt used was Chevron 200/300; the petroleum distillates were kerosine and an SAE-50 motor oil. The ethylene-vinyl acetate resins were produced by DuPont under the name Elvax.

Modifications of the NASA-developed thermoplastic material can yield a product with a wide range of physical properties suitable for various applications.

Various blended combinations of asphalt and plastic were evaluated by the SRI Polymer Technology Group in order to determine composition limits that would yield mixtures having good physical properties and reasonably low processing temperatures. In one series of asphalt-plastic mixtures, the molecular weight of the plastic was varied; in another, different plastics in varying

concentrations were used. Portions of these mixtures were then blended with oil and kerosine and the effects of this dilution noted. Various fillers were added to certain of the mixtures to determine effects on the properties. Mechanical properties were obtained on dog bone specimens prepared from these mixes. Tensile strength, elongation at break, and elastic modulus were calculated. No conventional methods of determining the softening point and penetration were used other than visual observations as to the ease of processing and pourability at mixing temperatures. Fillers and fluxing oils evaluated were generally waste products whose incorporation would be advantageous.

Incorporation of Elvax Ethylene-Vinyl Acetate Plastic in Asphalt

A rather wide range of Elvax ethylene-vinyl acetate resins was evaluated in asphalt. The major differences in these resins are the molecular weight and the ratio of ethylene to vinyl acetate in the copolymer. The resins evaluated are described in Table I.

Incorporation of Fluxing Oils in Asphalt/ Plastic Mixtures

Kerosine, SAE-50 motor oil, and used crankcase oil were evaluated as fluxing oils or diluents for the thermoplastic asphalt formulations.

Generally speaking, the low molecular weight copolymers melt at reasonably low temperatures but are lacking in strength and, conversely, the higher molecular weight copolymers are quite tough but have high melting points making processing with asphalt at reasonable temperatures difficult. It should be mentioned here that all mixing was done in a sigma type mixer at 250-300°F. These temperatures can be tolerated in commercial asphalt operations.

Polymer content in asphalt was varied between 12.5 and 50%. Obviously, higher polymer contents give a tougher product. Thus, the higher melt index polymers give higher tensile strength and modulus values for the corresponding thermoplastic asphalt mixtures. However, the processing difficulty increases with the higher melt

Table I

PROPERTIES OF ELVAX ETHYLENE-ACETATE RESINS

	Vinyl Acetate, %	Melt Index g/10 min ASTM-D1238	Soft. Pt, °F Ring & Bell ASTM-E28	Tensile Strength, psi ASTM-0882	Elongation at Break %	Elastic Modulus, psi ASTM-D882
Elvax 210	28	400	180	500	800	750
Elvax 310	24-26	400	190	400	800	1500
Elvax 350	24-26	19	280	1700	1000	2200
Elvax 360	24-26	2	370	2700	1000	2800
Elvax 410	18	500	190	420	370	2000
Elvax 420	18	150	210	850	550	2750

index polymers. Without a particular application in mind, it is difficult to determine a definite amount of plastic to incorporate into asphalt for optimal properties. However, it can be safely stated that all of the Elvax resins evaluated here are compatible with asphalt in amounts up to 50%. A cheaper, less viscous, more easily processed product is obtained with lesser amounts of plastic at a sacrifice in physical strength.

Kerosine was added in amounts of 10, 20, and 30%. In all cases, complete compatibility was achieved, but at great sacrifice in strength (proportional to the amount of kerosine that was added). Motor oil and used crankcase oil can be used interchangeably with no observed differences in physical properties or processing characteristics; however, motor oil is not as compatible with the asphalt-plastic mixture as is kerosine.

Incorporation of Fillers in the Mixtures

In addition to the standard tests performed on the various Elvax-asphalt-oil formulations, a program was initiated to determine

the effects of some fillers. Filler materials selected for the feasibility tests represent sources of pollution or waste products from manufacturing processes. Using these waste materials on a large scale would, of course, be ecologically desirable. Given below are the filler materials incorporated into the thermoplastic asphalt, with general description of the results achieved (see also Table II).

Ground Rubber Tires

Several types of ground rubber tires were readily incorporated into the thermoplastic asphalt during mixing. Viscosity of the mixture is determined by the texture of the ground rubber and the amount used. Finely ground rubber can be added in amounts up to 50% of the mix and not suffer serious loss of strength or required elongation. Coarse mixes, containing long pieces of rubber cord, can be processed but require considerably lower loadings to maintain a practical viscosity.

Buffing Dust from a Recapping Plant

One sample of buffing dust was incorporated into the thermoplastic asphalt in the amount of 35%. The sample mixed well but was quite viscous and had to be spooned from the mixer. This particular sample of buffing dust resembled lathe shavings more than dust. As a result, processing was more difficult. Pressed sheets looked quite good, however, and there is every reason to believe that buffing can be used advantageously.

Sulfur

Because of the great surplus of sulfur obtained as a by-product in industrial processes, it would be ecologically advantageous to find a large-scale use for this material. Several batches of thermoplastic asphalt were mixed with 10 to 50% amounts of sulfur added. The sulfur is easily incorporated and actually aids in the

processing. The mixing temperatures are in excess of the melting point of sulfur; therefore, the material is quite pourable. At mixing temperature, the sulfur appears to dissolve into the asphalt. Mechanical properties of the thermoplastic asphalt with 10% sulfur are comparable to batches containing no sulfur. In amounts over 10%, some loss of strength is observed, but mechanical properties are still satisfactory, even with loadings as high as 50%. Upon cooling to room temperature, the sulfur crystallizes to a very fine size. Thus, the final product may be defined as a homogeneous sulfur-filled thermoplastic asphalt. An ultra-thin layer of very fine sulfur crystals blooms to the surface on standing. For certain applications, sulfur could be a very useful filler material.

Glass

Samples of cullet and glass frit were obtained and incorporated in the thermoplastic material. For ease of incorporation, particle size of glass used was limited to minus 20 mesh. The samples mixed well, as the glass appeared to act as a processing aid. Viscosity of the mix was not adversely effected and the handling properties of the finished materials were considerably improved over the non glass filled version. Pressed sheets looked quite good and the material's utility in glasphalt applications seems feasible.

Used Crankcase Oil

Substituting used crankcase oil for fluxing oil appears to make no significant difference in the properties of thermoplastic asphalt. No valid objections have been found in the data collected thus far. Incorporating used oil in a particular formulation calling for a fluxing oil, in place of new oil, would have obvious ecological advantages.

Table II

EVALUATION OF FILLERS IN THERMOPLASTIC ASPHALT

<u>General Formulation</u>	<u>%</u>
Asphalt 85/100	72
Used Crankcase Oil	5
Elvax 350	24

<u>Filler Variables</u>	<u>% Filler</u>	<u>Tensile Strength psi</u>	<u>% Elongation</u>	<u>Elastic Modulus, psi</u>
Trastan 5PM	10	73	581	196
Trex DTA	10	51	382	182
Sulfur, Flowers of	10	48	432	196
Orzan	10	84	788	190
HRI 3219 Ground Rubber Tires	10	72	488	178
HRI 3219 Ground Rubber Tires	35	91	280	278
E9784 Ground Tire Fiber	10	78	116	322
E7329 Ground Rubber Tires	10	68	552	175
Glass Frit (-20 mesh)	10	38	200	nc*
Glass Frit (-20 mesh)	20	42	143	nc*
Lignosite	10	61	691	180
Raylig-261	10	81	822	185
Control-No Filler	0	72	645	200

* not calculated

<u>General Formulation</u>	<u>%</u>
Asphalt MC 250	60
Elvax 310	40

<u>Filler Variables</u>	<u>% Filler</u>	<u>Tensile Strength psi</u>	<u>% Elongation</u>
Glass Frit (-20 mesh)	10	21	57
Glass Frit (-20 mesh)	20	18	49
Control-No Filler	0	22	121

Table II (Continued)

EVALUATION OF FILLERS IN THERMOPLASTIC ASPHALT

<u>General Formulation</u>	<u>%</u>
Asphalt 200/300	62.5
Elvax 350	37.5

<u>Filler Variables</u>	<u>% Filler</u>	<u>Tensile Strength psi</u>	<u>% Elongation</u>	<u>Elastic Modulus, psi</u>
Control-No Filler	0	325	860	315
Sulfur, Flowers of	10	350	975	500
Sulfur, Flowers of	20	240	780	480

Paper Lignins

Paper lignins from several sources were incorporated into thermoplastic asphalt at a loading of 10% by weight. At this loading, mixing and pouring characteristics were quite good, and mechanical properties were similar to those of an unfilled control material. The mixing and pressing temperatures ranged from 250-300°F. It should be noted that in one case where the press temperature was excessively hot, decomposition of one of the lignins occurred, liberating large quantities of gas which created a foamed structure in the thermoplastic asphalt. This decomposition could be useful, perhaps leading to the development of a foamed thermoplastic asphalt for applications such as insulation. A means must be found, however, to cool the material rapidly to prevent foam collapse.

Impact of the Proposed Application

The feasibility study, conducted under the NASA Technology Applications program, was designed to investigate general properties of the improved thermoplastic material. The resulting information should provide interested parties with a basis for determining their

continued interest. Some potential applications of this material include special-purpose paving, waterproof membranes for bridge deck protection, sealants, roofing, resilient backing for synthetic turf, coatings, and membranes for land fill operations. The proposed applications are currently in the conceptual stages only, and each use will require individual study by the interested industrial or public sector organization.

**NASA TECHNICAL
MEMORANDUM**

NASA TM X-68257

NASA TM X-68257

**THE RESTORATION OF OBLITERATED STAMPED SERIAL
NUMBERS BY ULTRASONICALLY INDUCED
CAVITATION IN WATER**

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TECHNICAL PAPER proposed for presentation at
Twenty-ninth Semiannual Seminar of the
California Association of Criminalists
Palo Alto, California, October 17-19, 1973

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ABSTRACT

Seventeen out of 21 obliterated stamped serial numbers on test specimens of copper, brass, steel, and aluminum were successfully restored. Cavitation induced in water by a piezoelectric transducer was the mechanism used. Primarily, smeared metal was removed from the number grooves by the force of the cavitation, however, numbers were also restored at depths at or below the level of the stamped grooves. The feasibility of this technique as a low cost tool for crime laboratories has been clearly demonstrated. The technique is applicable to a variety of materials, and no previous surface or chemical treatments are necessary.

THE RESTORATION OF OBLITERATED STAMPED
SERIAL NUMBERS BY ULTRASONICALLY
INDUCED CAVITATION IN WATER

by Stanley G. Young

Lewis Research Center

SUMMARY

The identification characters, SRI 8368, were stamped on specimens of copper, brass, steel, and aluminum, and then partially obliterated by grinding at the Stanford Research Institute. These specimens were then submitted to the NASA Lewis Research Center for studies of the effects of a new restoration technique. The restoration mechanism was cavitation in water induced by the ultrasonic vibration of a piezoelectric transducer. All the stamped numbers and letters were completely or partially restored on specimens of copper, brass, and steel. Two out of five of the original numbers were restored on aluminum. (The aluminum specimen was originally used for optimizing variables in the restoration process. These variables were separation distance between specimen and vibrator, vibrator power, amplitude, and test time. Temperature and frequency were held constant.) On the copper specimen smeared metal was removed from the number grooves by cavitation. On brass all the numbers appeared in the form of a light-reflecting haze that was slightly brighter than the cavitation damaged background. This was unexpected because the measured depth of grinding was deepest in this specimen - about the same as the depth of the stamped numbers. In steel smeared metal was removed from the number grooves; however, one deeply ground number was restored in a manner similar to the numbers on the brass specimen. In aluminum, letters outside the region being attacked by concentrated cavitation were restored, but not those within the region, indicating that the first attempts of number restoration on this specimen were too severe. After standardized conditions were established, seven new numbers were



stamped on the aluminum, obliterated by grinding, and restored by this technique. Again, smeared metal was removed from the number grooves.

The important conclusion herein, is that the feasibility of this restoration technique has been clearly demonstrated. The method is recommended for use in crime laboratories as a relatively low cost technique that can restore serial numbers on most materials with the minimum of preliminary surface preparation.

INTRODUCTION

Serial numbers on stolen property or guns are often removed by filing or grinding. On recovered property, it is necessary to restore the numbers sufficiently so that they may be read or photographed before they can serve as evidence. In recent years, aluminum and metals other than iron and steel have been increasingly used for vehicles, tools, firearms, etc. (ref. 1). A number of restoration methods exist for each of these types of metals, but they involve chemical (ref. 2), magnetic, dye penetrant, or heat treatment methods. Also, each method is usually unique for the type of metal being examined, and many of these methods allow the numbers to show up only temporarily, with great skill being required to gain the needed photographic evidence. Furthermore, the specimen usually requires a series of mechanical and chemical treatments such as grinding, polishing, and etching, before the numbers can be seen. These treatments all run the risk of losing any residual traces of the numbers due to the restoration technique itself.

A new low cost method has been proposed (ref. 3) which appears to have universal application for serial number restoration on all materials; and which requires no prior surface treatment before the restoration process begins. The technique is based upon the method of ultrasonic etching of metal, accomplished at the NASA Lewis Research Center, reported in Tech Brief 71-10099 (ref. 4). The apparatus, variables, and results of ultrasonic etching, in which cavitation is the etching mechanism, are described in reference 5. Briefly, a magnetostrictive transducer is used to generate ultrasonic vibrations, which are transmitted through a layer of water to the metal specimen. Cavitation

bubbles in the ultrasonically excited water produce preferential etching of metal phases or grain boundaries, depending on the relative material properties. This effect was examined in the previous work on a microscopic basis, but had not been studied on a macroscopic basis at magnifications low enough to include stamped serial numbers.

The objective of this work was, therefore, to investigate the utility of the ultrasonic etching technique as a valid, low cost laboratory tool for crime laboratories, capable of restoring obliterated serial numbers on a variety of metallic materials with minimum surface preparation.

This paper reports the results of ultrasonically induced cavitation applied to obliterated serial numbers on copper, brass, steel, and aluminum. The samples were first stamped with letters and numbers, and then the identification numbers were totally or partially obliterated by grinding at the Stanford Research Institute. The effect of cavitation test variables such as temperature, specimen-vibrator separation distance, and ultrasonic power, amplitude and frequency are discussed and optimum test conditions are established where possible.

MATERIALS, APPARATUS, AND PROCEDURE

Materials

Specimens of 99.9 percent copper (Rockwell hardness RB-39), yellow brass (RB-63), low carbon steel (RB-93), and 99.8 percent aluminum (RB-66) were stamped by the Stanford Research Institute (SRI) with the numbers and letters shown in the photomicrograph of figure 1. Each specimen was stamped with the letters and numbers S, R, I, 8, 3, 6, and 8; and an additional specimen number was also stamped on each. The top specimen in figure 1 is copper (1), then brass (2), next steel (3), and aluminum (4) is at the bottom. Some of the numbers and letters were ground off using a grinding wheel, in a manner typical of unauthorized serial number removal on stolen property. The specimens were submitted to NASA by SRI in the condition shown in figure 2. The numbers and letters S, R, 8, 3, 6, and 8 were ground off the copper; 8, 3, 6, and 8 were ground off the brass; S, R, 8, 6, and 8 were ground off the steel; and S, R, 8, 6, and 8 from the aluminum - a total of 21 obliterated numbers and letters.

Apparatus

A schematic drawing of the apparatus used for the serial number restoration process is shown in figure 3. It consists of a piezoelectric transducer assembly driven by a power supply, which converts 60 Hz electrical energy to 20 000 Hz electric energy. Cavitation bubbles are induced in water at the tip of the transducer and the force of the collapsing bubbles is directed to the specimen immersed in the water directly below the vibration head. The bubbles attack weaker portions of the specimen and, in this instance, removed smeared metal from the grooves of the stamped serial numbers on copper, steel, and aluminum. The apparatus shown here was purchased for a total cost of approximately \$1500. A positioning table or holder of some type should be added to any standard laboratory set up. A magnetostrictive transducer was used in the work of reference 3 instead of the piezoelectric type used in the present study. The piezoelectric transducer used here was more efficient, gave a higher vibration amplitude, and was less expensive.

Test Conditions

The aluminum specimen was used to determine the effect of separation distance and ultrasonic power on the damage pattern. These two conditions were varied on the as-received specimen and also on the specimen after it was polished. Short bursts of cavitation attack (from 1 to 30 sec) were applied with separation distances varying from 0.5 to 1 mm and power varying from one-third to full. The conditions giving the most uniform haze were observed to be 1 mm at full power (150 W to the transducer). The damage patterns resulting from these optimized test conditions are the haze areas mostly on the left half of the specimen, shown in figure 4. These conditions were held constant for all of the other materials. The vibration frequency was 20 000 Hz and amplitude was about 0.1 mm. Tap water was used as the cavitation media. The temperature was held to approximately 20⁰ C ($\pm 2^{\circ}$ C). A detailed study of test conditions and the resulting amounts and types of damage can be found in reference 5.

Procedure

The as-received specimens were examined very closely by low power binocular microscope; and visible traces of the numbers or letters were recorded. Low magnification ($\times 1$ to $\times 2$) photomacrographs were made of each specimen and $\times 10$ to $\times 20$ photomacrographs were made of individual portions of the specimens before ultrasonic treatment. The specimens were then placed in the water bath, temperature was adjusted and the transducer was operated for various time increments. After each increment, the specimens were removed, visually examined and photographed using various methods of lighting. Some specimens were examined by scanning electron microscope at approximately $\times 30$ and higher to record depth effects and mechanisms of material removal.

RESULTS AND DISCUSSION

The photomacrographs of the specimens of copper, brass, steel, and aluminum are shown at various magnifications in figures 5 to 18.

Copper

Figure 5 shows $\times 1$ photomacrographs of the copper specimen. Observations of this specimen before the restoration process indicated that grinding was not too deep; however, all letters and numbers except the I had been obliterated beyond immediate visual recognition. In very short times (3 to 5 min) some of the numbers were recognizable and in 20 minutes all the obliterated numbers and letters were restored enough to be recognized. The numbers and letters are more easily seen in figure 6 at $\times 2$ and figure 7 at $\times 6$. Various methods of oblique lighting helped to highlight the numbers and letters.

In figure 7 the number 3 that was restored after 5 minutes is starting to be obliterated by the cavitation attack (see the pitted region on the 20-minute photomacrograph of fig. 7). For this reason care must be taken to start the restoration process in very small time increments at first, so as not to destroy the numbers and letters restored in the early phases of the test. On this specimen and on some of the other materials,

penciled circles were drawn around suspected locations of numbers, and these show up on some of the 0 minute photomicrographs (white circles on fig. 7 - 0 min). These pencil markings were automatically removed during the first few seconds of cavitation attack.

In order to clearly show the mechanism of material removal, Scanning Electron Microscope (SEM) photomicrographs were made of the number 8 shown on the lower right of the photomicrographs of figure 7. These photomicrographs are shown in figure 8. At 3 minutes most of the smeared metal was still in the grooves; however, cavitation had partially loosened some of the metal, so that the outline of the 8 was discernible from the surrounding metal. At 5 minutes, large chunks of the metal were removed and at 10 minutes nearly all the smeared metal was removed. At 20 minutes, the remaining metal was removed; but areas where metal was removed earlier were starting to show severe pitting from the cavitation attack.

Brass

Photomicrographs of the brass specimen at $\times 1$ are shown in figure 9. The numbers 8, 3, 6, and 8 were removed. This specimen was ground more deeply than the others - approximately to the bottom of the stamped notches. The measured depth of grinding was as deep as 0.40 mm while the stamped letters and numbers averaged depths of only approximately 0.37 mm. It was therefore surprising when numbers reappeared in this specimen. From the $\times 1$ photomicrographs at longer times in figure 9 and the $\times 5$ photomicrographs in figure 10, all the numbers have been completely restored and show up in the form of a light haze on a darker background. Under low power binocular observations, the regions of the numbers appeared more reflective in spots than the cavitation damaged background, but higher magnification microscope examinations did not detect observable differences between the two types of surfaces. Further work would be needed to discover the exact mechanism of restoration in this case. But it probably involved differences in attack due to work hardening at the notches of the stamped letters and numbers. Nevertheless, this work indicates that restoration

by the ultrasonic technique can be successful even though the numbers have been removed to depths at, or slightly below, the bottom of the stamped numbers.

Steel

In steel the letters and numbers S, R, 8, 3, 6, and 8 were originally removed. The ground surface was quite irregular. The restoration process in steel was a combination of the mechanisms of number restoration in copper and brass. Some numbers were restored by smeared metal removal, while another number, which had been ground more deeply, was restored by the appearance of a light haze. Figure 11 shows $\times 1$ photomacrographs of the steel specimen at times out to 120 minutes. Most of the numbers and letters are readable. At 0 minutes, the circles and numbers shown are pencil indications of areas of interest. These markings, as mentioned before, were quickly removed by the cavitation at the start of testing.

Many different types of lighting were used to try to show up the letters and numbers. Figure 12 shows the restored letters and numbers S, R, 8, and 3 at times from 0 to 70 minutes. The letters and numbers are highlighted by oblique light to show up light on a darker background. In figure 13, at the same magnification, the letters are dark on a lighter background. This was caused by using a sharper oblique lighting angle and rotation of the specimen to allow light reflection from the original grinding marks. Both methods, however, show up the letters quite clearly. Smeared metal was removed from the grooves of the stamped numbers and letters.

Figure 14 shows the partially restored numbers 6 and 8 at $\times 8$, at times to 70 minutes. Because these numbers were not clearly visible, when all other numbers were obvious, much longer test times were allowed over this specific region of the specimen. Figure 15 shows the results on the steel specimen at the end of the test. Attack was discontinued on the region of the S, R, 8, and 3 after 120 minutes, but the test was continued to 220 minutes over the region containing the 6 and 8. From the bottom photomacrograph of figure 15 at $\times 6$, the 6 can now be

seen almost in entirety as a light haze. The 8 is still only partially visible, but better than before.

A SEM study was made on the number 3 of the steel specimen and the photomicrographs from this study are shown in figure 16. Magnification range is from $\times 30$ to $\times 9000$. At the high magnification, the steel has a very jagged, torn appearance as a result of the cavitation attack, indicating that even in steel, cavitation is starting to attack the surface of the restored number after long test times.

Aluminum

In the aluminum specimen the S, R, 8, 6, and 8 had been removed. This was the only material for which all of the original obliterated numbers were not at least partially restored. Several reasons may account for this lack of number restoration. First, the aluminum was used as a preliminary test specimen to determine effects of test variables on cavitation damage results. Second, the aluminum base metal may have been attacked as easily as the smeared aluminum. Initial attack was too severe, and slight differences between smeared metal and base metal were masked. The letters S and R however, were restored, but they were just outside of the region of high intensity cavitation attack. Photographs describing restoration methods and results for the aluminum specimen are shown in figure 17. Figures 17(a) and (b) show $\times 1$ photomacrographs of the aluminum at 1 and 5 minutes. Separation distances ranged from 0.5 to 3 mm. At 5 minutes the S and part of the R are visible and, if the viewer has a good imagination, he can see part of the last 8, although this was not counted as part of the successful restoration. Once optimum conditions had been established, new numbers and letters were stamped on the aluminum specimen and ground off by NASA. Six of the seven numbers and letters were entirely restored by the mechanism of smeared metal being removed from the grooves by cavitation (see fig. 18). The N which had been ground most deeply was partially restored. It is believed that the regions beneath the stamped numbers of this originally hard aluminum were not affected by the stamping as were those areas of the brass and steel.

In general, the method described in this paper, of restoring obliterated serial numbers without initial metallographic grinding or polishing, has been very successful. Further work would be useful to more completely understand the potential and applicability of this method to serial number restoration, particularly in determining the effective depth of restoration.

SUMMARY OF RESULTS

The identification characters, SRI 8368 plus a specimen number (1, 2, 3, or 4), were stamped on copper, brass, steel, and aluminum and then partially obliterated by grinding at the Stanford Research Institute. The obliterated serial numbers and letters were completely or partially restored at the NASA Lewis Research Center by cavitation induced by ultrasonic vibration in water. Seventeen out of 21 obliterated numbers or letters were permanently restored.

1. On copper, all the obliterated letters and numbers S, R, 8, 3, 6, and 8 were restored. Smeared metal was removed from the letter and number grooves by the cavitation.

2. On brass, the obliterated numbers 8, 3, 6, and 8, after cavitation exposure, all appeared in the form of a light haze, which was observed in flat light more easily than in oblique light. This result was unexpected because the grinding was deepest in this specimen. (Measured depth of grinding was about the same as the depth of the stamped numbers.) An ability to detect disturbed metal below the stamped numbers and letters is indicated here.

3. On steel, the letters and numbers S, R, 8, and 3 were completely restored and the 6 and 8 were partially restored. As in the case of copper, smeared metal removed from the grooves was the primary mechanism. After longer exposure times the partially restored number 6 was observed in the same manner as were the numbers on the brass specimen.

4. The restoration process on aluminum was a partial success. The original letters S and R were restored but numbers 8, 6, and 8 were not. This material was the first tested, and was used to establish optimum test conditions for the other materials. It is believed that the

initial cavitation conditions used for this material were too severe, and that the residual differences between the grooves and smeared metal were rapidly removed by the cavitation before photographic records were made. Later, new numbers and letters were stamped on the aluminum, obliterated by grinding, and restored using the previously established optimum test conditions.

CONCLUDING REMARKS

The high degree of success achieved in the restoration of stamped numbers and letters demonstrates the feasibility of this technique as a useful crime laboratory tool. This restoration technique has major advantages over chemical or magnetic methods because no prior surface treatment, such as grinding and polishing, is necessary, and it appears to be applicable to a variety of materials. Also, while only temporary restoration is possible with many of the other methods, this method provides permanent restoration of the numbers.

The metals, with the exception of brass, were not ground too deeply. Thus, this method was found to be a type of very high intensity "ultra-sonic cleaning" method which removed smeared metal from the grooves of stamped letters and numbers, leaving the stamped surfaces relatively undamaged. However, another mechanism may be operating when the grinding is deeper. The brass specimen and part of the steel specimen were ground to depths approximately equal to the depth of the original stamped numbers. Yet, after cavitation attack, the numbers appeared quite clearly as a lighter haze on the darker background. Low magnification showed brighter surfaces in the number regions than observed in the surrounding material. It appeared that the deformed metal beneath the numbers was damaged in a manner different from the surrounding metal. The difference in damage was probably due to work hardening at the notches of the stamped letters and numbers. Further study of the effect of the restoration technique at depths below the number is recommended.

This serial number restoration technique appears to work on a diversity of materials, and it is dependent on differences in the materials

due to the mechanical deformation involved in the stamping process. Therefore, it is suggested that stamping be considered in preference to other methods of applying numbers during the manufacturing process. The numbers would then be more permanent because it is extremely difficult to remove all residual traces of them.

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3. Chisum, W. Jerry; and Parker, Brian: Potential Application Report, Problem SRI/C-30, Obliterated Serial Number Restoration, Apr. 27, 1972.
4. Young, S. G.: Ultrasonic Metal Etching for Metallographic Analysis. NASA Tech Brief 71-10099, 1971.
5. Young, Stanley G.: Etching of Metallographic Specimens by Cavitation. Proceedings of the Third Annual Technical Meeting of the International Metallographic Society, 1971, pp. 167-185.

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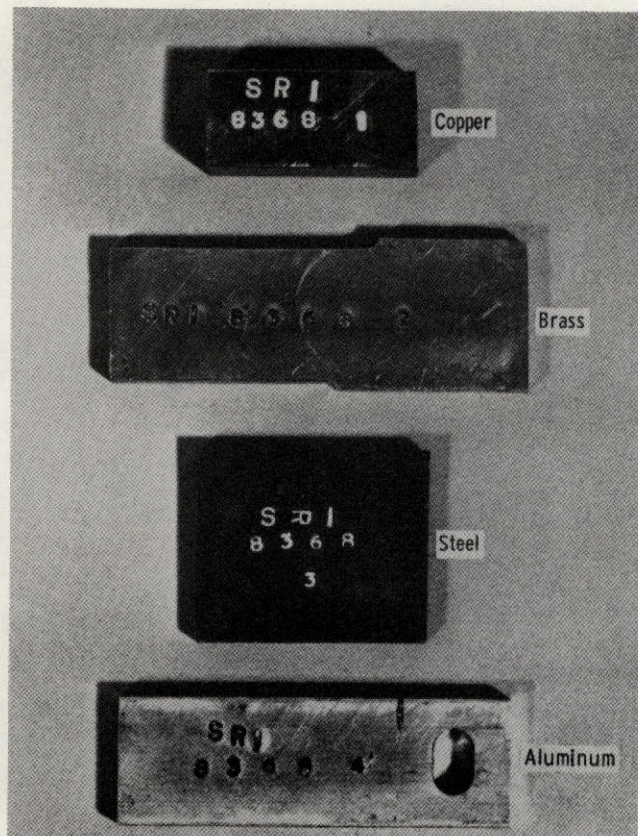


Figure 1. - Photograph of specimens of copper, brass, steel, and aluminum with serial numbers stamped by the Stanford Research Institute.

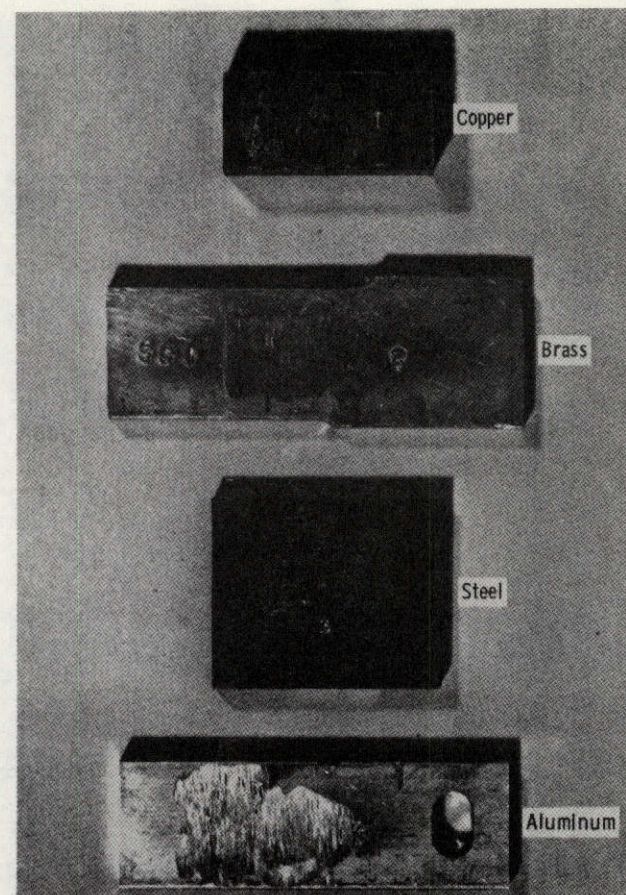


Figure 2. - Photograph of specimens of copper, brass, steel, and aluminum with serial numbers ground off by the Stanford Research Institute (as furnished to NASA.)

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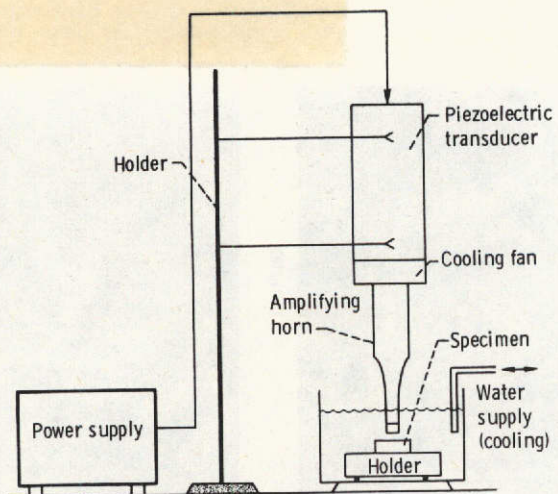


Figure 3. - Schematic diagram of test apparatus used to restore serial numbers by ultrasonically induced cavitation.

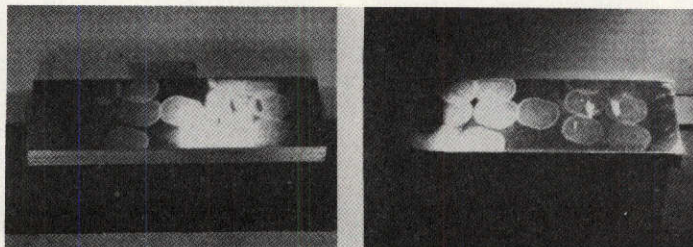
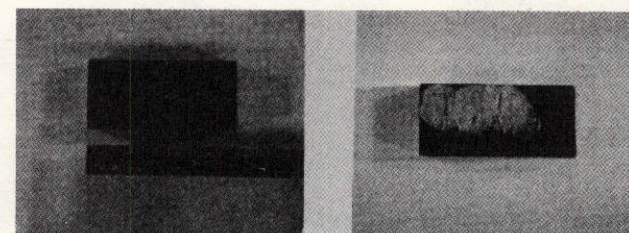
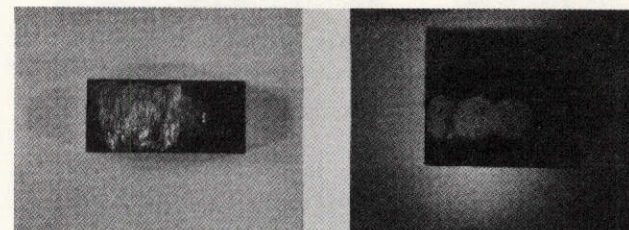


Figure 4. - Polished specimen showing cavitation damage haze patterns caused by exposures from 1 to 30 seconds at varying separation distances (two photos of same specimen at different light angles).



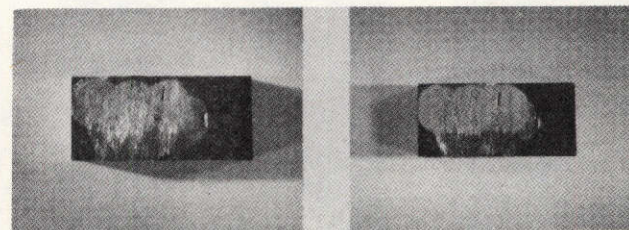
0 minutes

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3 minutes

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5 minutes

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Figure 5. - Photomicrographs of copper specimen subjected to cavitation, showing serial number restoration at various exposure times - X1.

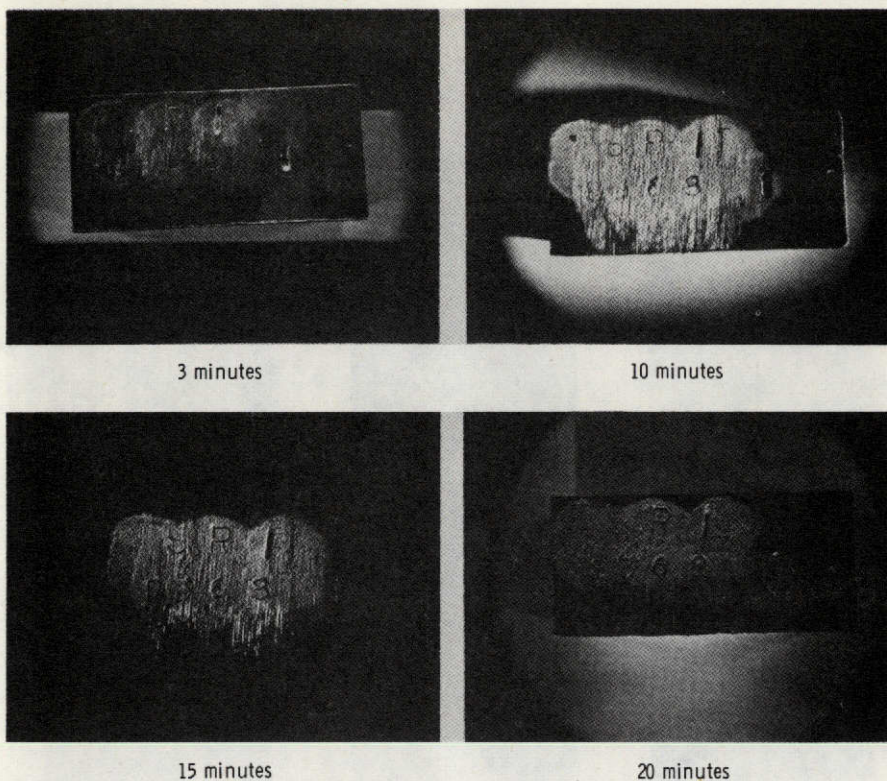


Figure 6. - Photomicrographs of copper specimen subjected to cavitation, showing the restored letters and numbers at various exposure times (high intensity oblique lighting - X2).

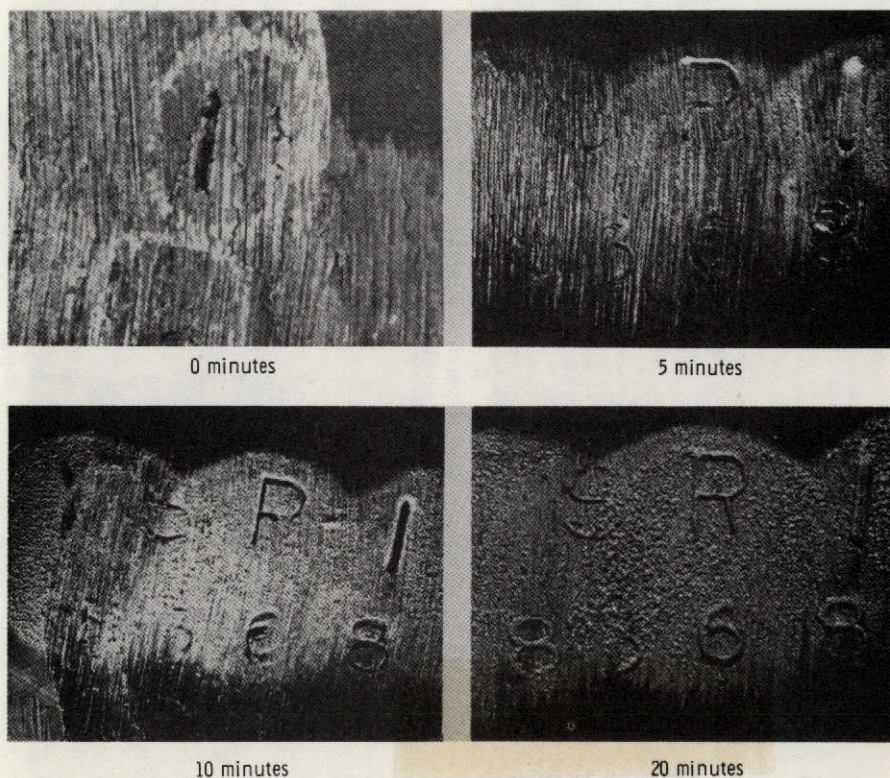


Figure 7. - Photomicrographs of copper specimen subjected to cavitation, showing the restored letters and numbers at various exposure times. - X6.

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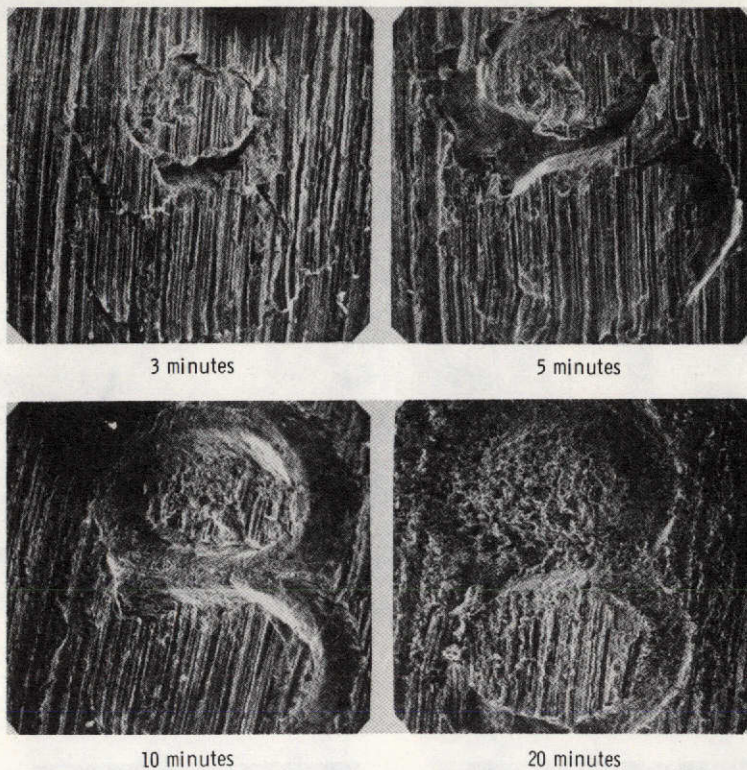


Figure 8. - Scanning electron photomicrographs of number 8 on copper specimen in the process of being restored. Smeared metal being removed from the grooves - X30.

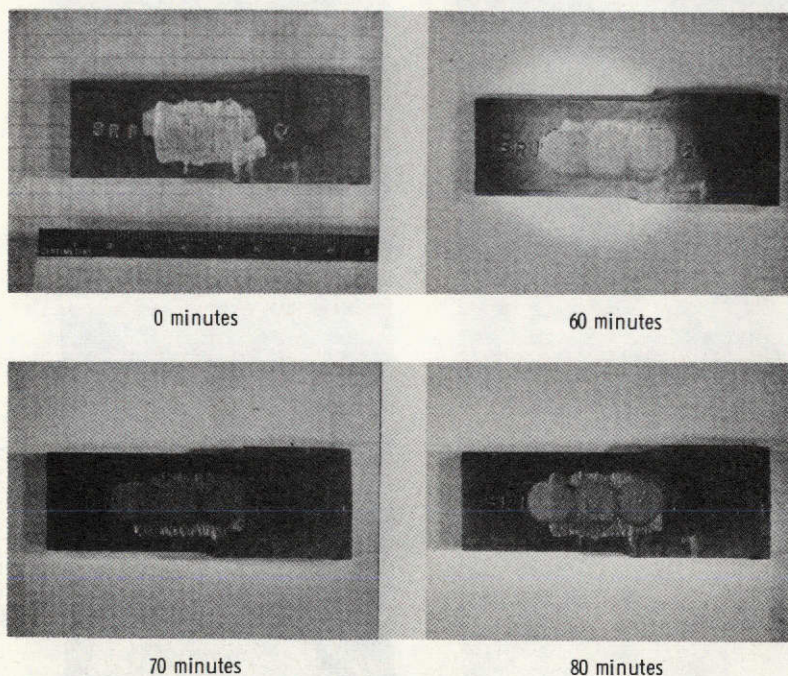


Figure 9. - Photomicrographs of brass specimen subjected to cavitation, showing serial number restoration at various exposure times - X1.

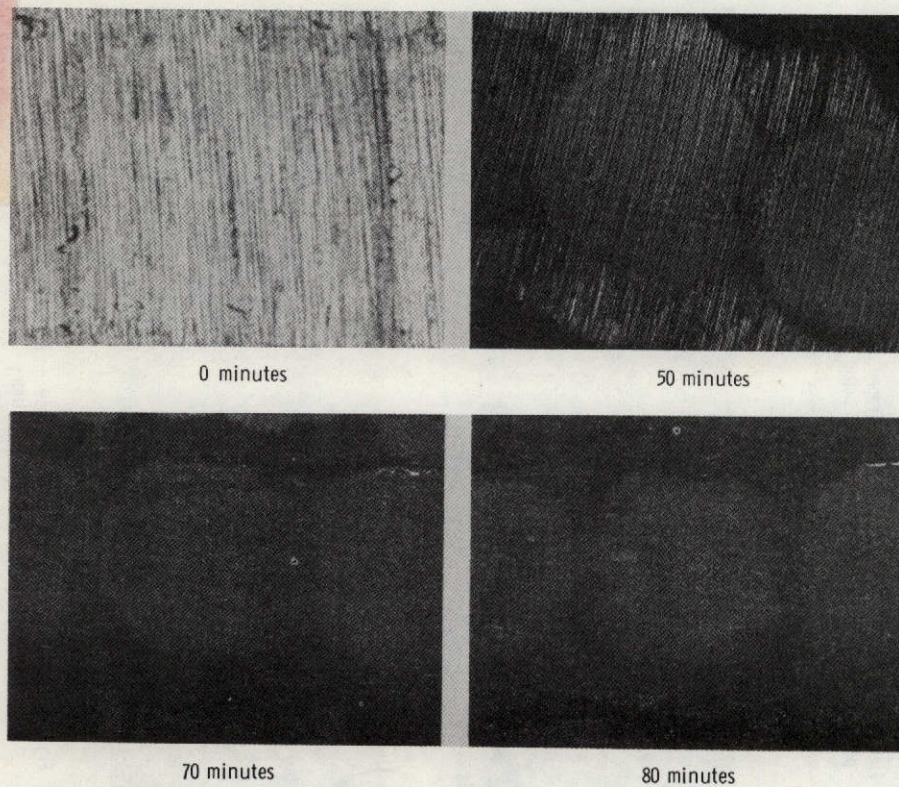


Figure 10. - Photomicrographs of brass specimen subjected to cavitation, showing serial number restoration at various exposure times - X5.

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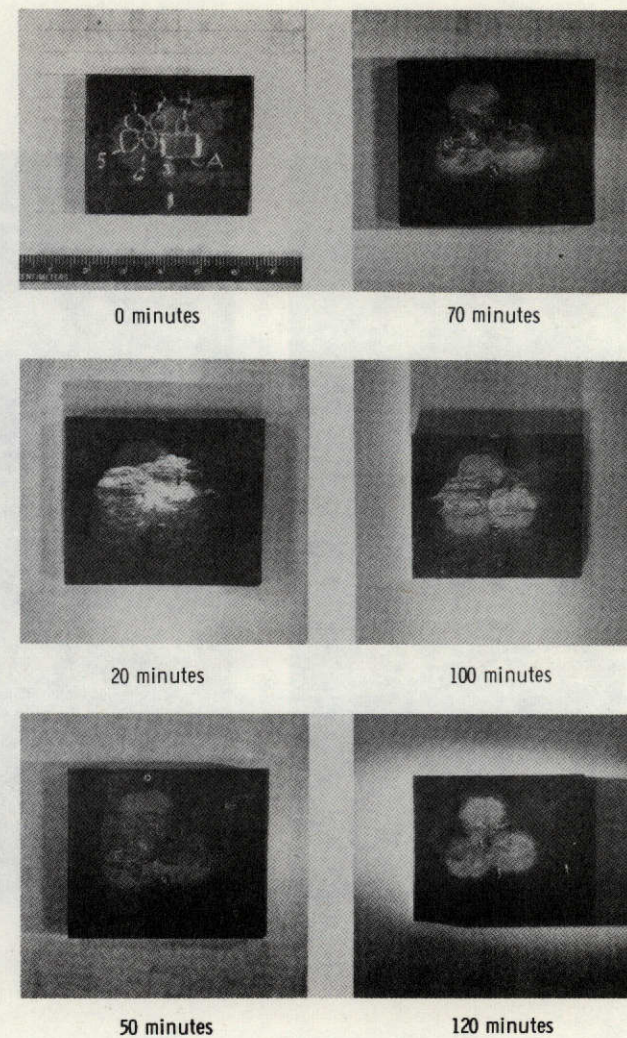
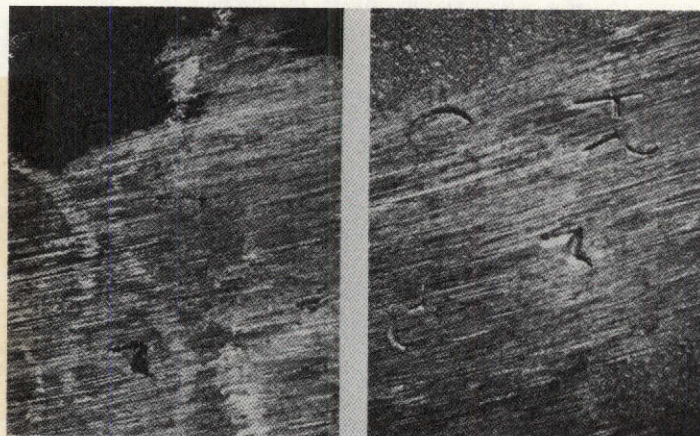
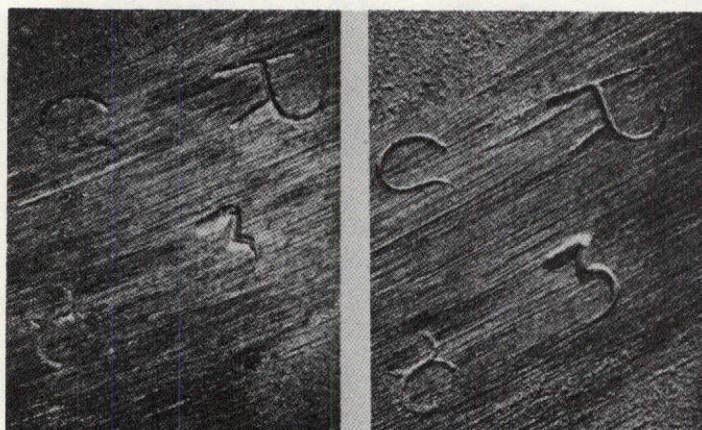


Figure 11. - Photomicrographs of steel specimen subjected to cavitation, showing serial number restoration at various exposure times - X1.



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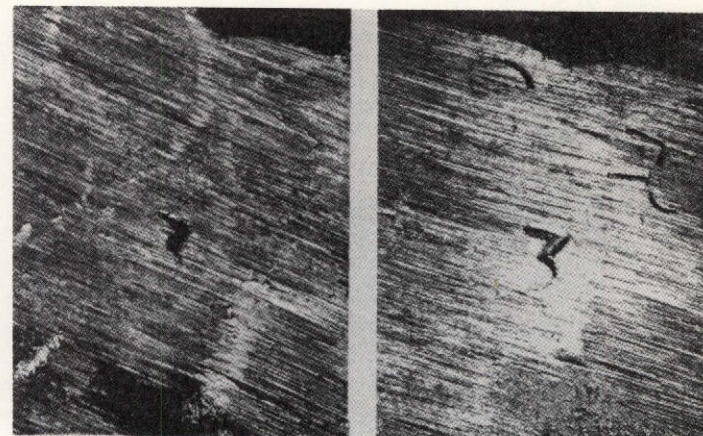
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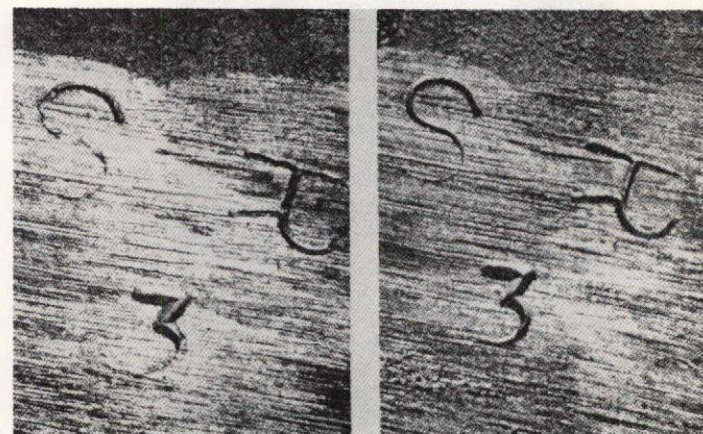
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Figure 12. - Photomicrographs of steel specimen subjected to cavitation, showing the restored letters and numbers - S, R, 8, and 3, at various exposure times (letters highlighted on dark background by oblique light - X8).



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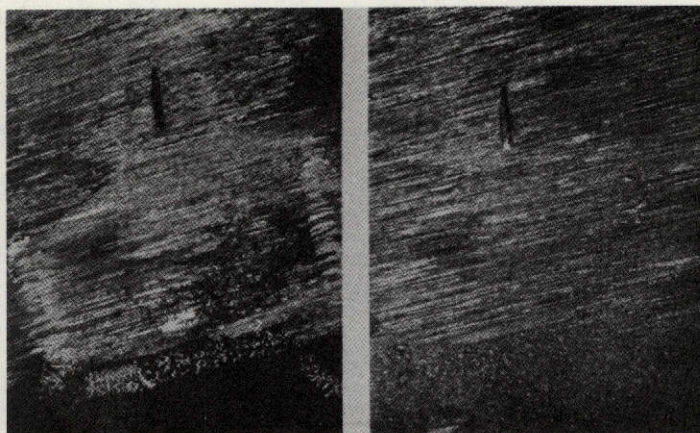
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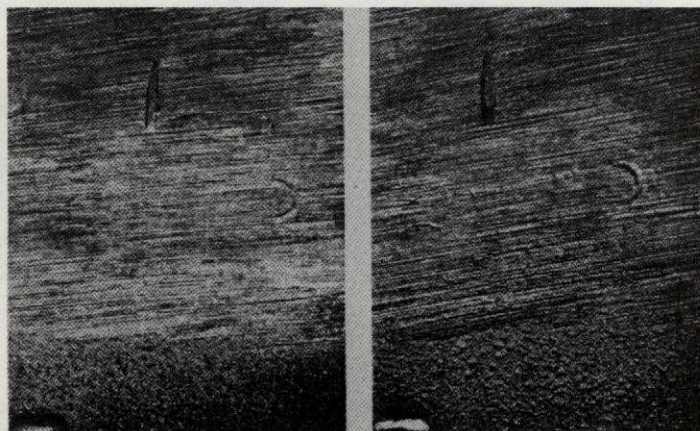
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Figure 13. - Photomicrographs of steel specimen subjected to cavitation showing the restored letters S and R, and the number 3, at various exposure times (letters dark on light background - X8).



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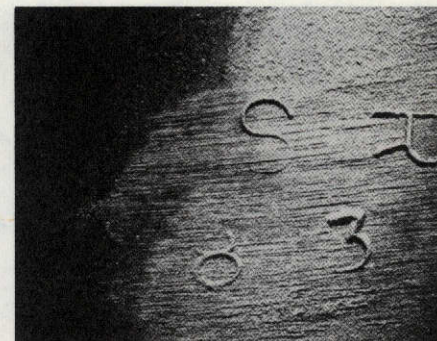
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Figure 14. - Photomicrographs of portions of steel specimen subjected to cavitation, showing the partially restored numbers 6 and 8, at various exposure times - X8.



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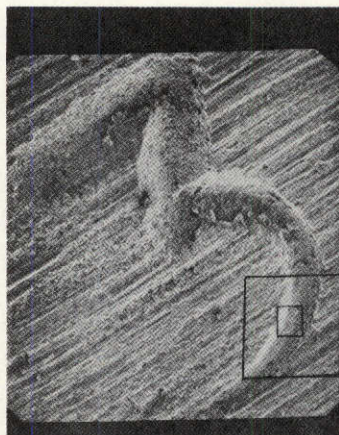


220 minutes

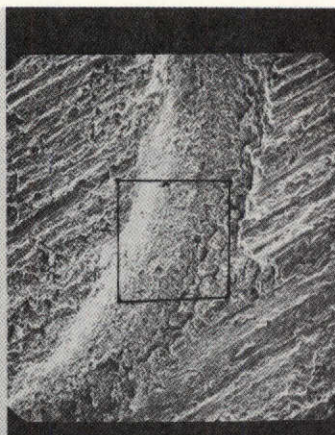
Figure 15. - Photomicrographs of restored letters and numbers on steel specimen at end of experiment - X6.

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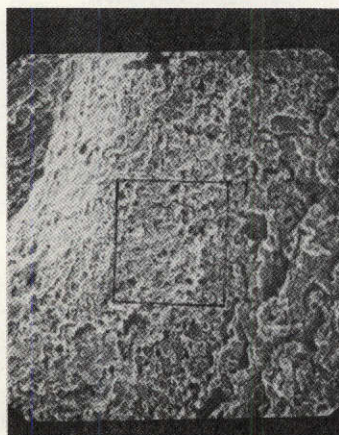
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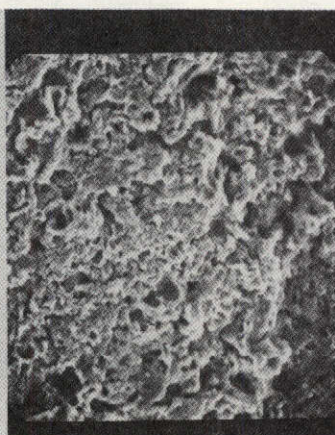
X30



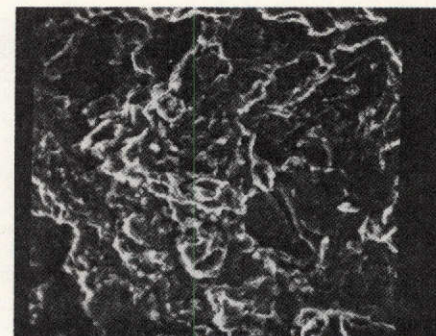
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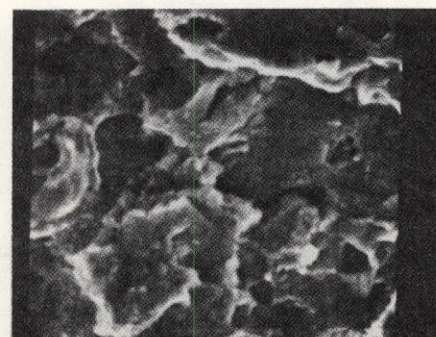
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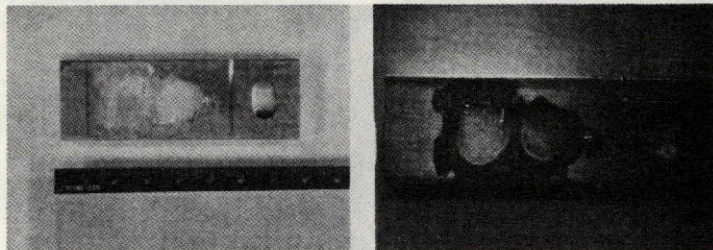
X3000



X9000

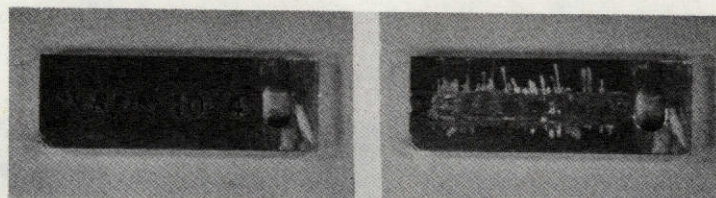
Figure 16. - Concluded.

Figure 16. - Scanning electron microscope photomicrographs of restored number 3 on steel at various magnifications after 120 min. exposure to cavitation.



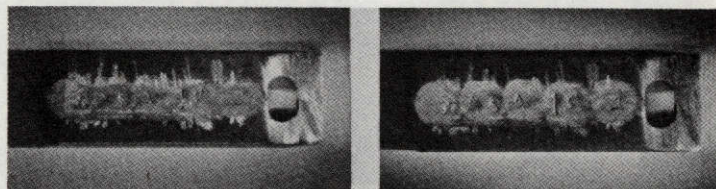
(a) 1 minute cavitation - uniform light. (b) 5 minutes cavitation - oblique light.

Figure 17. - Photographs of aluminum specimen showing results of initial attempt to restore letters and numbers.



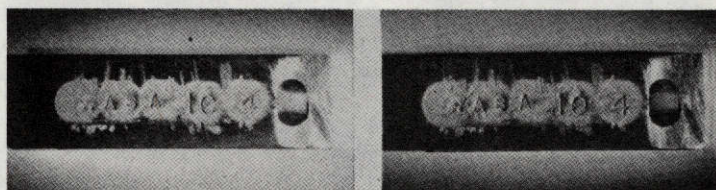
As-stamped

Identification obliterated



3 minutes cavitation

5 minutes



10 minutes

20 minutes

Figure 18. - Results of serial number restoration by cavitation on aluminum specimen. (Identification stamped and obliterated by NASA).

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TECHNOLOGY TRANSFER

NASA has amassed a wealth of technology in the course of the USA aerospace program. How to put this helpfully to use in the public sector was described in a recent project report, reprinted in part herewith.

An active effort is being made by the National Aeronautics and Space Administration's Technology Utilization Office to transfer technology from the USA aerospace program. One aspect of this effort matches problems in the public sector with solutions in the aerospace knowledge bank. A Technology Applications (TA) Team performs this function at several interdisciplinary research institutes, interacting (a) with public-sector people who can define the problems and (b) with NASA scientists and engineers who can bring technology to bear on the problems.

One such activity takes place at Stanford Research Institute (SRI) where a NASA-sponsored Team has operated for more than three years. Its objectives include the transfer of technology to help solve problems in transportation, criminalistics and postal service. Coupled with this is development and application of methodology to achieve such transfer, particularly ways to decrease the time gap between development and marketing of new technology. Another objective is to aid the movement of knowledge across industrial, disciplinary and regional boundaries.

This particular TA Team developed a methodology that includes adaptive engineering of aerospace technology plus commercialization when a market is indicated. They concluded that commercial businesses must enter the process to transfer technology successfully. How to bring this about is described in Section II of SRI Project Report PYU-8368, Contract NASW-1992, reprinted herewith for your information.

The National Aeronautics and Space Administration has application teams at several research institutes working on technology transfer between aerospace and the public sector. This is being done through NASA's Technology Utilization Office. One of these teams, at Stanford Research Institute, made an annual report that tells, among other things, how the group worked out a procedure for the purpose. The accompanying excerpt from the report deals with methodology resulting from interaction with 58 public sector agencies during 1972.

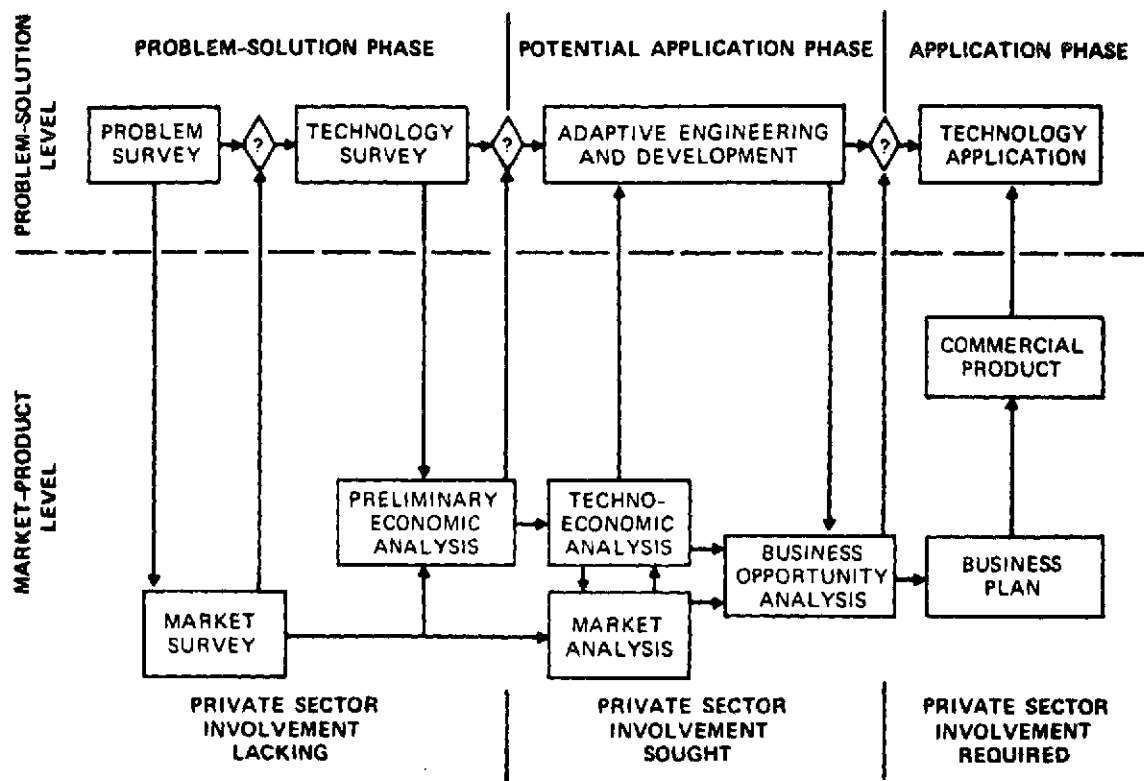
The methodology of the SRI TA Team has evolved to the point where it is apparent that commercial businesses must enter the process in order to transfer technology successfully. The Team member acts as a third-party transfer agent, interacting with the people who can define public sector technological problems, the NASA scientists and engineers who can bring technology to bear on these problems, and the businessmen who can convert the technology into products that solve the problem within the technical and economic limitations imposed by the market.

The Team member has certain functional activities to perform through the various phases of technology transfer. The nature of these functional responsibilities varies, depending on the level at which the transfer activity is pursued and the involvement of private interests in the process (see Figure 1). These activities are superimposed on the phase and level of the transfer process, according to the extent of business involvement.

The technology transfer effort may remain at the problem-solution level if it is apparent that a commercial product or service will not be needed eventually. This is the case when the technology involved is a one-of-a-kind piece of hardware, a technique, or a new way of combining off-the-shelf hardware to meet certain ends.

When it is apparent that a legitimate solution will require a commercial product, it is essential to approach technology transfer at the market-product level. The TA Team member is no longer merely solving a technological problem; he is identifying a market. A transfer can be successful only when the business aspect is addressed as well as the technical aspect. They must be pursued in parallel so as to reduce the risks associated with technical, market, and investment development.

Decision points exist throughout the phases of the transfer process. For conceptual purposes, three discrete decision points are shown in Figure 1. At these points the TA Team must ask: Is there a problem (market)? Is there a potential solution (potential product)? Is there a real solution (busi-



TA-8368-25

FIGURE 1 FUNCTIONAL ELEMENTS OF A TECHNOLOGY TRANSFER PROGRAM

ness opportunity)? The parenthetical terms must be substituted at the market-product level of the transfer process. The functional elements, shown in Figure 1 and discussed below, provide the information needed to answer these questions properly.

Figure 2 indicates the types of information that must be obtained and the activities that must be carried out in each of the functional elements. These elements are interrelated to provide all information necessary for decisions that will permit proceeding from one phase of the transfer process to the next in a timely manner.

The transfer process begins when an apparent problem is subjected to a problem survey. The survey must establish a consensus on the validity, importance, and impact of the problem, and must define any constraints that should be imposed on the solution. If the solution will involve a commercial product, it is essential to conduct a market survey to identify products that address the problem, indicate the size of the existing market, show

the price that may be paid to solve a problem, and indicate present shortcomings in meeting the needs of the market.

The problem survey and, when necessary, the market survey provide information necessary to determine whether to proceed in trying to find solutions. If the decision is affirmative, these surveys will also provide the input to a search strategy for the technology survey element of the transfer process. In differing circumstances, this survey can be broad, encompassing the open literature and computer data bases, or narrow, zeroing in on certain technologies and certain individuals expert in these technologies. Once solutions are identified, they must be screened for feasibility. This may require effort on the part of the organizations that present the problems or those that hold the solutions.

At the market-product level, feasibility indicates more than the ability to solve a problem technically. A solution is not feasible at this level if it is not commercially sound. The preliminary

"Does a real business opportunity exist?"

This question must have an affirmative answer".

"Only when a commercial product becomes available can the problem-originating public sector agency benefit from the technological solution . . ."

economic analysis is thus needed to determine the projected cost of the future technology-based product in quantities consistent with the expected market. If the costs are excessive, can something be done to bring them in line? The technology survey and the market survey will provide some of the necessary input for this analysis. The preliminary economic analysis itself will be essential in determining whether there is a potential solution (product) worth pursuing.

Adapt existing technology

If it appears that a reasonable cost can be achieved, the transfer process can move into the potential transfer phase. At the problem-solution level this phase may require an adaptive engineering and development program to convert existing technology to its new use. Uncertainty as to whether the potential solution is real and practical may still exist and must be eliminated through the adaptive engineering and development program. At the market-product level, the potential transfer phase is more complex. The adaptive program cannot proceed in a technoeconomic-market vacuum. In addition to converting the application of technology from one use to another, the program must reduce costs, improve capabilities, and generally optimize the technology in light of the needs imposed by the new market. This can be accomplished only if the market is analyzed and understood, and a technoeconomic analysis is performed that defines the scope and objectives of the adaptive engineering and development program.

Detailed analysis necessary

The market analysis is quite different from the market survey mentioned earlier. Whereas the market survey centers around a problem, the market analysis centers around the potential product that may solve the problem. Given a potential product, the Team must determine how it will be used, how it will be acquired, what barriers could prevent its use, and how to overcome such barriers. The Team must also determine the market segments and resultant product variation requirements, and an acceptable price range. These factors will affect the design, engineering, and development of the new product.

The preliminary economic and market analyses form a basis for the technoeconomic analysis. The desired performance spectrum and the technology-based limitations are examined, cost performance trade-offs investigated, and production and distribution considered. Consideration is given to pertinent noneconomic aspects as the analysis leads to the definition of an appropriate adaptive engineering and development program. There is, of course, some interplay between the market analysis and the technoeconomic analysis, requiring that they proceed somewhat in parallel.

In a business opportunity analysis, the technoeconomic-market analysis is updated and the results of the adaptive program are factored in. The investment and risk are reevaluated to determine the potential for adequate return. Does a real business opportunity exist? At the market-product level of the transfer process, this question must be answered in the affirmative.

Getting the parties together

Figure 1 indicates that this potential application phase is a transition area as far as business interaction is concerned. A lack of business involvement in the first phase leads to the utilization of the transfer process, while the last phase cannot be accomplished at the market-product level without business involvement; hence this must occur in the middle phase of the process. If the business community is to take up the transfer, the right firm(s) must first know all about the potential application and become convinced that the investment risk is commensurate with the expected return. When public funds are involved, the announcement of a business opportunity derived from public needs and public technology must be made openly in a publication such as the Commerce Business Daily, or introduced into the private sector in conformity with other national objectives, such as aid to small businesses.

In any case, companies can become involved at any point in the transition phase of the transfer process. Ideally, a company will see enough potential prior to the technoeconomic-market analysis and adaptive engineering program to assume the cost of these functions. In some cases, however, the potential will not be sufficient until risk is re-

duced through these functions.

A transfer occurs at the problem-solution level when the particular public sector agency assumes the responsibility for implementing the solution that was found and adapted through the transfer process. The Team's function at this point is to ensure that user responsibility is properly exercised and that essential feedback is received by NASA.

At the market-product level, a transfer occurs only when the solution becomes a commercially available product. Technical, economic, and market information may be provided by the Team to interested companies considering production. Only when a commercial product becomes available can the problem-originating public sector agency benefit from the technological solution, which is provided by an active transfer program. □

PROBLEM SURVEY

- Problem definition
- Benefits from solving problem
- Consensus on nature and priority of problem
- Constraints on solutions
- Previous attempts at solving problem

MARKET SURVEY

- Commercial product requirement
- General market characteristics for this product
- Other products on the market
- Companies manufacturing these products
- Description, specifications, and price of each product
- Shortcomings of each product

TECHNOLOGY SURVEY

- Technology previously investigated
- Reasons for unsatisfactory results
- Technology relevant to the problem
 - Review open literature
 - Search appropriate data banks
 - Contact experts
 - Circulate a problem statement
- Proposed solution(s) worth pursuing

PRELIMINARY ECONOMIC ANALYSIS

- Projected production costs
- Cost comparison with available products
- Ways to reduce costs
- Potential savings due to
 - Extended product life
 - Lower maintenance costs
 - Product use
- Overriding non-economic benefits

MARKET ANALYSIS

- Product use
- Product procurement
- Appropriate communication and distribution channels
- Barriers and hurdles
- Size of market segments
- Product variation requirements
- Appropriate pricing schedule
- Expected future changes in the market
- Dynamics of the market in response to a new product introduction

TECHNO-ECONOMIC ANALYSIS

- Performance spectrum for the new product
- Performance limitations imposed by new technology
- Cost-performance tradeoffs
- Important non-economic considerations
- Scope of appropriate adaptive engineering and development program

ADAPTIVE ENGINEERING AND DEVELOPMENT (AED)

- Accomplish the engineering and development necessary to:
 - Reduce costs
 - Simplify operation
 - Improve performance
 - Meet all market-imposed requirements
 - Optimize product design for expected application
- Produce, test, and demonstrate prototype(s) as appropriate
- Make necessary design changes

BUSINESS OPPORTUNITY ANALYSIS

- Changes in the techno-economic and market analysis based on the AED program and exogenous considerations
- Investment requirement to bring the developed technology to the market
- Expected risk/return relationship for the investment
- Does the adapted technology constitute a valid business opportunity

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FIGURE 2 ANALYSIS OF A TECHNOLOGY TRANSFER PROGRAM

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